Science and Sustainability

Selected Papers on IIASA's 20th Anniversary

THE INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS

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To promote international cooperation in solving problems arising from social, economic, technological, and environmental change

To create a network of institutions in the national member organization countries and elsewhere for joint scientific research

To develop and formalize systems analysis and the sciences contributing to it, and promote the use of analytical techniques needed to evaluate and address complex problems

To inform policy advisors and decision makers about the potential application of the Institute's work to such problems

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Foreword

IIASA celebrated its twentieth anniversary on May 12–13 with its fourth general conference, *IIASA '92: An International Conference on the Challenges to Systems Analysis in the Nineties and Beyond.* The conference focused on the relations between environment and development and on studies that integrate the methods and findings of several disciplines. The role of systems analysis, a method especially suited to taking account of the linkages between phenomena and of the hierarchical organization of the natural and social world, was also assessed, taking account of the implications this has for IIASA's research approach and activities.

The conference was attended by roughly 200 scientists and policy makers from 24 countries in Europe, the Americas, Africa, and Asia, as well as from a number of international organizations. Papers were commissioned from fourteen authors under four broad themes: the environment, technology and economic transitions, systems methodology, and social forces and the unity of scholarship and action. These papers were the focus of fourteen workshops, each of which had two designated discussants, a rapporteur and a chair. During the plenary session addresses were given by, among others, Dr. Franz Vranitzky, Federal Chancellor of Austria, Dkfm. Ruth Feldgrill-Zankel, Austrian Federal Minister for the Environment, Youth and Family, Academician Guri Marchuk, a former President of the USSR Academy of Sciences, and Professor Godwin O.P. Obasi, Secretary General of the World Meteorological Organization.

This volume is the first of two books to result from the conference. In this collection, we have attempted to select those papers presented at the conference that dealt with environmental issues and the role of science in addressing such problems, as well as to some extent creating them. We hope that we have been able to capture some very different styles of expression and, more importantly, of thought. The second volume will contain all those papers not included here, as well as the discussants' and rapporteurs' comments. It will indicate the broad range of topics covered by the conference.

Our thanks are due to the Institute's National Member Organizations for their steadfast support, to the Austrian Federal Ministry for Science and Research for their special grant for the conference, to the participants of the conference for their many contributions, and to all the IIASA staff members who worked so hard to make the conference the success that it was.

Peter E. de Jánosi
Director, IIASA

Vladimir S. Mikhalevich
Chairman, IIASA Council (1987–1992)

Introduction

The word sustainability greatly influenced thinking on environment and economic growth from the moment of its use by the Brundtland Commission. It has caused scholars as well as the general public around the world to pause and reflect on where civilization is heading, including what the countries starting to industrialize are letting themselves in for. Not many words uttered by a committee have ever had so much resonance.

One might think from this that the word means something – that it draws the attention of its numerous users and hearers to some particular "thing". Such is not the case. It has attained its effect by the very fact that to each listener it brings to mind a picture suited to his or her preconceptions. One will hear it as saying that we can keep going on the present path just as we are now doing, with more and more goods, a better and better life for ever more people. Another hears it as warning that on our present path we are destroying the environment within which our economy and society sit, the way that locusts do, except that for us there is no moving on to another site. Between the extreme contrast of a happy future that nothing can stop, and its opposite of total destruction that it is now too late to prevent, every possible implication of the word comes to mind when the word sustainability is uttered. The one common element in the varieties of usage is that sustainability is good; no one opposes it.

Not many years back such differences in the way that people looked at the world would have been attributed to class, but now that is out of style. The best we can say in its place is that the rich can afford to take the future into account, while the poor have to concentrate on eating today. However, that does not account for such facts as that many an Asian peasant is above all anxious to turn his half-hectare of land over to his son with its fertility intact, while the rich American lives to the limit of his credit cards.

Much of the variation in the meaning of sustainability arises through different preconceptions about trends in our ways of production and consumption and the power of science to accommodate them within the natural environment. The point can be exemplified with fossil fuel. Will burning coal and oil prove our undoing? Yes, argue some; for one thing we will exhaust the natural sources of fuel, but long before that happens we will suffocate ourselves with the emissions from their combustion, as well as making intolerable changes in the world climate. Of course our use of energy is sustainable, say others, because just as we have changed from wood to coal to oil, so we will continue to change: science will surely find a way to produce fusion power within the next 20 years, and then we can move into the hydrogen economy based on a practically infinite source of energy, and where emissions contain nothing more harmful than H_2O.

Sustainability in the latter view does not mean standing still, but continuing the course of scientific progress, whose future benefits we can anticipate from what it has done for us in the past: and if there are unintended effects they can be countered by the foresight of people and governments. Thus it is true that methods of attracting and capturing fish have become so efficient that they threaten the survival of fish populations, but we already see action on the part of governments to offset this excess of efficiency.

Yet at least a vigorous minority of the scientists on whom this progress depends express limited confidence in the ability of science to achieve what non-scientists expect of it. Science does not automatically rectify the unfortunate effects that it introduces. Mass tourism made possible by the world air network destroys many of the objects, natural and manmade, that attract tourists. The widespread distribution of modern firearms upsets political stability wherever the institutions of civility are weak. Agriculture has attained unprecedented yields, but the reckless use of the fertilizers on which the farmer now depends encourages unwelcome algae.

Both of these contrasting viewpoints are represented in this volume. For Guri I. Marchuk, as for Tokio Kanoh and Umberto Colombo, there may indeed be some temporary difficulties with our kind of progress, solvable by technical means that science will develop or else by social rearrangements that will be readily agreed on. On the other hand, for Sheila Jasanoff, Helga Nowotny, and Andrzej Wierzbicki the power of science to serve us is less assured. They record the numerous questions that a public which has recently become suspicious is asking. Just at the moment when they are enjoying more of the fruits of science than ever before in history, publics have suddenly discovered behind the facade of science fallible human beings. While few refuse the benefits of science, all seem to enjoy reading about its difficulties and uncertainties. Our authors give substance to public doubts when they point to discoveries within science that suggest some basic limitations, ultimately limits to human rationality itself.

It is good to have agreement on a word, even if the word has a thousand meanings. The next stage beyond such agreement is to apply a maxim of scholasticism: never assert, seldom deny, always distinguish. It is not too early to look into the meaning of the word. That has been done before, but by no one as acutely as by Harvey Brooks in the introductory paper he contributed to the conference and to this volume. A prominent physicist, a master of science policy, Brooks does not indulge in assertions in which the lack of meaning is compensated for by the emphasis with which they are presented. He wants first and foremost to know what we are talking about.

After this initial essay, the volume is laid out in terms of one aspect or another of sustainability, starting with the optimistic side. First come the papers by Marchuk, Kanoh, and Colombo, working from the premise that what we are now doing in technology and the economy can continue for the increased benefit of more and more people. The second group of papers, those of Golitsyn, Jasanoff, Nowotny, and Wierzbicki, perceives some less satisfying elements in our present and prospective condition. They are not willing to take the promise of the 18th century Enlightenment on faith, but look closely at the ways in which science has fallen short of that promise, or if not science itself then the way that science has been used.

Every participant in the conference, the optimists as well as the pessimists, agrees that we need to know more. For any discussion of sustainability hard data on the present is of interest largely insofar as it points to what the future will be like; the question is how the positives and the negatives of trends discernible now will affect our children and grandchildren. The pessimists would be relieved if they could be sure that the ratio of negative to positive will be no worse today than it was a hundred years ago.

That needs forecasts, and these are always uncertain. To extrapolate the present for the short-term future, especially when things are changing gradually, and where a simple causal structure applies, can indeed provide useful guidance. However, none of those three conditions apply to environmental predictions: they are long term, the subject of their prediction can change suddenly, and their causal relations are exceedingly complex.

In short, we live in a world in which forecasting is both indispensable and impossible. One of our writers is bold enough to try. Lawrence Klein extends the well-tested methods of econometrics to incorporate ecological and demographic variables.

Oran Young faces up to the fact that scientific knowledge will not change matters in the world as long as it stays in the laboratory. Nor is communicating with leaders sufficient. Democratic politics tends to punish politicians who move too far ahead of their constituents. Successful politicians are careful not to move too fast, and they are often the last to acknowledge the urgency of the need for action. When national leaders get together in international meetings, in the "anarchical society", they do what they think will please the voters back home. Young shows how a popular network can be created that will push politicians in whatever science determines is the right direction for the planetary future.

The last of the workshop papers is by Léon Tabah on population growth, mostly concentrating on the Third World. Any measure for attaining sustainability that does not deal with the human population, and that fails to take account of the three-quarters of it that lives in the developing countries, is a non-starter. The environment of this three-quarters is now partially protected by their being poor. However, no one anticipates the perpetuation of low incomes, and if large populations do not themselves inhibit development, then the movement of the poor up the economic ladder will have a drastic effect on the biosphere, the natural setting of nations and the world. Poverty damages the environment in one way (poor people overcut for firewood) while wealth damages it in other ways (rich people use more energy), but the rich, having more command of resources, can do more damage.

Ten of the eleven papers listed above (the exception is the paper by Guri I. Marchuk), along with five other papers reserved for later publication, were each presented in draft form to a workshop in which participants in the conference interested in the particular subject could question, comment, criticize, and point to alternative possibilities. Discussion in relatively intimate groups (though some of the workshops were chosen by as many as 50 participants) permitted all to have some input. The papers as subsequently revised make up the main content of this and the succeeding volume.

This book is both part of the record of the conference of May 12–13, 1992, and a celebration of IIASA's first 20 years. It starts with a welcoming address by Chancellor Vranitzky of Austria, under whose policies IIASA's host country has gone far toward reconciling economic progress with measures of conservation. It concludes with a statement by Director Peter E. de Jánosi sketching what the conference will mean for IIASA's research activities in the years ahead.

The remaining papers, as well as the prepared statements of discussants and the workshop records made by rapporteurs, will be published as soon as possible.

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PLENARY ADDRESS

Opening Remarks

Federal Chancellor Franz Vranitzky

Twenty years is a proud anniversary. In human life, but also in the life of organizations, it marks a point when – after inevitable deviations, detours, and experiences – one has reached more or less solid ground, has established oneself as a distinct personality and sees a much clearer path for future development.

In driving out here today, I reviewed the past 20 years of IIASA's existence, the incredible changes which have occurred in this relatively short span of time, the many "ups" which gave us hope and perspective, the many "downs" which we had to, and finally did, overcome.

When the decision on IIASA's foundation was taken, we wanted to prove that intensive cooperation among scientists – irrespective of the constraints of political systems and ideological differences – is *possible*. Today, conscious of the changes in the political map of the world, but also in the awareness of the problems which confront us, we know that it is not only possible, but that it is *inevitable*.

Thus, in 1972 it was a step of great courage, but also a step of great political wisdom and farsightedness, that brought together here in Laxenburg this group of scientists of international distinction, with one objective: to work together and to pool their wisdom and their creativity toward the solution of global problems that are interlinked and affect each other.

Today, IIASA can look back at a proud record of achievement: it has firmly established itself as the central place to which governments, but also other research-oriented institutions, can turn for sound advice and information. The role which IIASA has played in the preparations for UNCED 92 in Rio de Janeiro, or, for instance, in the conference on the water resources of the Middle East, which will be convened this month in Vienna and will address an eminently political issue and an issue central to any peace agreement in the Middle East, amply proves my point.

We are all in agreement that we live in an interdependent world and that the burning questions which confront us are interlinked and intertwined. We know that the eruption of a volcano on the American continent can and will affect the European climate. We know that a slight deviation in an ocean stream can strongly influence a country's economy. We know that the oil fires in Kuwait damaged the ecological balance of the Himalayas, we know about the importance of the rain forests and the dangers of deforestation, we know about the damage done to the ozone layer, we know about how damage to one system correlates with damage to another.

Is it thus not surprising how difficult it still is to draw the necessary conclusions from this knowledge, to arrive at a joint program of action, and to subordinate short-term national interests – or interests that may be perceived as such – to a long-term common good?

The preparatory work for UNCED 92, the international conference that was called with such great hopes and such ambitious goals, has clearly shown that there is still a wide gap between the rational acceptance of scientifically established facts and the political action needed to remedy existing damage and to prevent further deterioration. What was designed as a large-scale learning experience for the industrialized and the developing countries alike, as a joint effort of truly global scope, now runs the danger of becoming submerged in petty mutual accusations and reproach, in preaching and protesting, and in haggling over finances. The safeguarding of our global environment runs the danger of becoming subordinate to the safeguarding of narrow national interests and small-scale economic advantages.

I do not want to sound unduly pessimistic, but all the signals are there and point in this direction. We will all, scientists and politicians alike, have to join forces, work very hard, and be very persuasive to overcome the present impasse.

Shortly before his death Sir Isaac Newton stated, and I quote: "I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me." We have the privilege of incredible progress in charting the great ocean of truth. Now it is our task to convert knowledge into political action and to transfer the international cooperation which characterizes the world of science into the world of politics.

The concern about the global environment provides the most stunning and the most obvious example of how the traditional definitions of the nation state, its power, and its prerogative to exercise national sovereignty are changing. As a consequence, we are obliged to reassess many assumptions that have formed the basis of our national political institutions.

National borders in Europe, as well as in other parts of the world, are losing their importance. Trans-national corporations span the globe, and in many cases have significant influence on national economies. National institutions cannot but lose political relevance if much of the decision making is no longer taking place in the various capitals, but does so jointly and in a cooperative manner at international conferences, or – as is the case in Europe – in the headquarters of the European Community in Brussels. Thus, the very concept of national sovereignty is changing its meaning. Today, sovereignty is less exercised by free and independent decision making and more by participating as an equal partner in those organizations where decisions that have an unavoidable impact on one's own affairs are taken.

However, national institutions are not only affected by the growing weight of supra-national institutions and the increasing relevance of supra-national cooperation. They are also affected from below – by a growing interest in local and regional autonomy, and by a growing tendency for people to turn to the communal or regional context for definition and self-expression.

We have to find a rational balance between these two, seemingly countervailing, trends: the need for supra-national cooperation on one side, the yearning for identity and the smaller scale on the other. Institutions like IIASA, for whom international cooperation is a natural fact of their existence, also have much to contribute to this debate.

On this basis, I want to offer my sincere congratulations on IIASA's anniversary, combined with my best wishes for its future and my hope that it will continue to flourish and prosper. On behalf of the Austrian Government I can assure you that not only are we proud to be your host here, but that you can always count on our support and our assistance.

Award

Before I conclude, there is a very pleasant task I have to perform, a task for which this meeting provides the ideal background. I have already referred, at the beginning of my remarks, to the founding fathers of IIASA and their ideas, and there are first and foremost two names which immediately come to mind: Professor MacGeorge Bundy and Academician Gvishiani. Unfortunately, Professor Bundy is not with us today, but it gives me great pleasure to confer here publicly on Professor Gvishiani the "Grand Gold Decoration with the Star", which the Austrian Federal President has bestowed on him. Academician Gvishiani, in this audience it will be unnecessary to describe your distinguished academic record or your great achievements for IIASA and international scientific cooperation in general. Let me assure you that we are deeply conscious of everything that you stand for and what you have always contributed to the good relations between Austria and your own country. It is with great personal pleasure that I give this decoration with my sincere congratulations and my best wishes for your future.

Chancellor Vranitzky presenting Academician Gvishiani with his award.

Plenary Address

Current and Future Global Challenges

Guri I. Marchuk

Before the onset of every new century, questions relating to the science of the future always used to arise among scientists. We, the scientists of the 20th century, encounter the same questions. Only 8 years remain until the 21st century begins, and if one takes into account that the biggest breakthroughs in science and technology require about 15–20 years of hard work, then one understands that we have to define the trends in the development of science and technology for the beginning of the 21st century in the very last years of this century.

It seems to be an extremely difficult task at first sight. But, as analysis shows, forecasting trends in science is quite possible since we enter the new century armed with several powerful technologies. They represent the accumulated potential of the past and will serve in the future as a source of great potential for the knowledge which has not yet been used in practical applications.

The second half of the 20th century brought many significant discoveries into our life. Examples are supercomputers and system robotechnology, space objects, nuclear energetics and thermonuclear synthesis, polymers and artificial fabrics, biotechnology for the production of proteins, genetic engineering, composite materials, accelerators for colliding neutrons and plasmotrons, and many others.

But together with all these, the 20th century brought into the world atomic and thermonuclear weapons, intercontinental missiles, strategic air forces and navies, as well as the systems to destroy them. Unfortunately, this is not all. The environment is being severely damaged due to intensive contamination by transport, industrial wastes, and poisonous agricultural chemicals. The pollution process occurs on both a regional and global scale and influences the planet as a whole. It makes our current way of life very complicated, as well as that of future generations. These are the problems we enter the 21st century with.

Up until the last decades the role of anthropogenic changes in the biosphere was negligible, since nature nearly always had the capacity for regeneration, and this fact was solidly embedded in the consciousness of man: man used to consider these regeneration capacities as limitless ones. However, fast development of science and technology brought completely new factors into the attitude of man to nature. The destructive forces of technology released by man proved to be of the same order as those of nature. These include not only atomic and thermonuclear energy, but also anthropogenic changes in the environment which are caused by harmful industrial wastes and which destroy the biosphere. Unprecedented acceleration of industrial and agricultural production has already placed our planet in a really dangerous situation in the 20th century. Therefore, with the 21st century approaching, it is necessary to conceive new ideas to solve scientific and technological problems in order to preserve the habitat of man.

One could note quite definitely that the main challenge to science in the 21st century is the problem of the preservation of the biosphere and the survival of man in the conditions of global change in the climate and biosphere: that is, all of the environment as a system. This system has already been subjected to very negative anthropogenic changes. Therefore, science and technology in the 21st century should be applied to answer the main question: what are the stability boundaries of the biosphere? That is, they should be used to develop man's understanding of which changes in climate, pollution, and man's industrial activity will not substantially change the state of the biosphere and will not cause it to evolve into a new, irrecoverable form.

In order to approach this problem one needs new ideas and new knowledge in technology and biology. A sophisticated mathematical model is needed to describe the climate of the atmosphere and the oceans, and their interaction in the conditions of permanent changes in the biosphere. Ecology in this sense becomes the leading and uniting link in our knowledge of the habitat of all live beings on the planet.

The components of this link are many-fold. First of all there are the problems relating to the pollution of the atmosphere by products poisonous to the biosphere, such as discharges of harmful substances by industry. The amount of these substances has increased so as to endanger the very life of the planet. Therefore, one of the main tasks in the 21st century will be complete technological reconstruction with the goal of closed cycles in industry and natural biological defense against harmful insects and weeds in agriculture. This will result in numerous problems for science and technology. The development of the foundations of environmental protection will be the major problem of the end of the 20th and the beginning of the 21st century.

Let us begin with problems in energetics. Consider global pollution of the planet and how it influences the biosphere. First of all it is linked with the network of electric power stations, which work, as a rule, on coal and mazut and discharge enormous amounts of carbonic, sulfurous, and other gases which warm the atmosphere and contaminate the environment. Another big problem is freons and other nitrogen compounds: they destroy the ozone layer – the unique defense of the biosphere against disastrous ultraviolet radiation.

Therefore, no doubt, humanity in the 21st century will move on to new sources of energy, absolutely new technologies, and ecologically clean energetics. These are principally new methods of combustion and utilization of the wastes of electrical power stations. Such energetics are based on reliable nuclear stations. This means thermonuclear energetics based on "Tokomak" systems: these are powerful laser systems providing the necessary temperature for thermonuclear reaction in a tritium–deuterium medium. Another example is muon catalysis, possibly combined with breeders (fast-neutron reactors).

The whole of the scientific community was astounded toward the end of the current century by the discovery of high-temperature superconductivity. Literally hundreds of laboratories attacked this problem in order to gain new knowledge and find practical applications. Many things became clear, many others require thorough and complex analysis. Nevertheless, many experts agree that the 21st century will be the boom century in this field, which will bring about revolutionary transformations in such applications as the production of superpowerful accumulators of energy, energy transfer over long distances with no leakage, the construction of new elements for computers, precise apparatus to study the earth's ultraweak magnetic fields, and many others. This new direction, no doubt, will influence many fields of science and technology and might result in an unprecedented economy with ecologically clean energy.

Let us now consider the chemical industry. It seems to be the biggest source of planetary pollution and, together with mining and metallurgy, is a dominating factor in contaminating the biosphere. Acid rain, ozone concentration depletion, and chemical aerosol poisoning in the atmosphere in the vicinity of industrial centers have become the norm. The same might be said about automobiles, aviation, and other kinds of transport polluting the cities of the planet and whole regions of land and aerial space. All these damage people's health. Therefore, the automobile industry and machine-building plants for all kinds of transport will be the subject of technical rearmament in the 21st century. Cheap catalysts will appear as the basis of classical schemes to remove harmful wastes in transport: electromobiles and electroengines will appear as a result of technical revolution.

Chemical multi-stage processes will be gradually converted into few-stage or just one-stage ones. Plasmotrons and lasers of great power will form the basis of the technical rearmament of chemistry. Mechanochemistry – a new science which has already had initial success – will enter our life. It is capable of producing new compounds with no consumption of water, which is still the basis of all large-scale chemistry. However, it will require thorough research. The first requirement is the study of the synthesis of compounds on the basis of mathematical modeling of chemical transformations. Even now these studies begin to gather acceleration.

One may foresee that using new catalysts will result in the temperature of chemical reactions gradually approaching almost room temperatures, which are characteristic of most complicated chemical-biological processes going on in the cells of live organisms. The catalysts will again play a main revolutionary role here. The studies of live organisms and optimal technological processes will converge. Literally, such studies, together with studies of the human genome and genetic engineering problems, will create new possibilities for the chemical and biotechnical industry of the future.

Biotechnology, which is a colossal source of pollution, deserves special consideration. Classical technology for the most important product – protein – is based on processing organic compounds using bacteria. The production of protein on the basis of this technology is accompanied by discharges of numerous poisonous ingredients which get into the atmosphere and water basins and contaminate the environment with harmful wastes. This is a deadlock way to produce proteins and important pharmaceutical goods.

The recent results obtained at the Institute of Protein of the Russian Academy of Sciences suggest that protein could be synthesized by genetic engineering methods directly based on the replication of RNA. It is an ecologically clean technology which, no doubt, will dominate in the new century. This case convinces us once more that the ecological protection of the planet will principally stimulate new scientific ideas for the technology of production of proteins and medical preparations of broad usage.

Microbiology will be exclusively important for "clean" technology; it will bring about the creation of numerous bacteria strains utilizing fine-disperse waste products as a natural process of metabolism. Enormous dumps of processed matter on earth will be the source of nutrition for such microorganisms: extracting the latter would give many new, valuable substances. Even now, some laborious microbes concentrate fine-disperse gold, tungsten, and other elements. However, this is only the beginning.

Now let us consider biological monitoring. In order to observe the state of biota, biological monitoring is needed: this is carried out with the help of a system of satellites and reliable biological stations. A system of simple, cheap satellites will provide us with the possibility of monitoring the biosphere as a whole and collecting information for data bases in order to establish the trends in the changes of biota and to be able to use this information in any place on the planet. This is the very exclusive role of space monitoring. This task will be carried out simultaneously with the accumulation of global information on climate changes needed to establish variations in the climatic components of the whole planet and in separate regions. Of course, to process the data monitored concerning climate change, huge computer networks and reliable data bases will be needed. We shall return to this question later.

Space technologies will be of great value in the future. They will give mankind unique, new knowledge and products which are impossible to obtain in conditions on earth. These are materials with the extreme features of homogeneity needed for the electronics of the future, materials for medical preparations, composite materials, new, unique chemical compounds, and many others. The main problem affecting fast development of space technology is the source of energy needed for the realization of large-scale space projects. Science and technology must make provision for this: 100–500 kWt of energy is a good beginning for space production. Space in the 21st century will be actively rendered habitable by the use of manned orbital stations. All this will weaken ecological stress on earth and give people new, more effective, and cheaper means of survival.

Of course, space studies alone will not give the complete picture of biological and geophysical changes on the planet. Stationary installations are required on the surface of the earth. Scientists are already thinking of the construction of bio- and geophysical stations which will measure the biogeospheric background of the planet. It is important to begin by constructing along three meridians a series of five to seven such stations. It is possible to construct the first series on the Krasnojarsk meridian – from Taimyr through the tundra, through the mountain ridges of Pamir, through India to Sri Lanka. The second meridian of stations could pass through Great Britain, France, and Africa. The third meridian of stations could pass through North and South America. Processing the data collected by these biospheric stations equipped with the same apparatus will make it possible to get valuable information on the biological and geophysical background of the planet and link it with space monitoring. However, this requires interstate effort.

The energetics of the future are being developed right now based on utilizing solar energy in space and then transmitting it to certain points on the earth. So, underestimation of the scope for research efforts in "earth" space will result in big losses for mankind. Such excellent projects as the investigation of remote space by missions of manned stations toward Mars, and possibly to other planets of the solar system, are not considered here. They will considerably enrich our knowledge of the space around us and will provide a powerful incentive for the development of new theories and technologies, including earth-based technologies.

Monitoring the state of the land, atmosphere, and ocean will make it possible to establish the most important changes in the climate of our planet, taking into account anthropogenic factors. This means the development of a large area of fundamental and applied science concerning the planet Earth, global climate changes, the general circulation of the atmosphere and oceans, and the life of the biosphere.

Finally, let us consider mankind. Man lives in real conditions of changes in the environment, climate, and biosphere, and is part of the biosphere himself. He is subjected to the influence of ultraviolet radiation, X-rays, and γ-rays. Intensive radiation creates the conditions necessary for the accelerated mutation of cells and for the appearance of cancer cells which may lead to lethal cases. Man is subjected to attacks by antigens – viruses and bacteria which may result in considerable changes in the immune system of an organism since their influence is being enhanced by chemically active substances polluting the atmosphere and radiation. The immune system grows weak, bringing about the rise of chronic diseases and decreasing the lifespan of man. This requires a lot of research to support man's recovery, and to correct his immune system, including the use of artificial antibodies – we already know how to produce them using hybridome methods.

On the eve of the 21st century humanity is experiencing an optimistic page in its history, namely, the process of nuclear disarmament which substantially decreases the probability of nuclear war. Both in the Commonwealth of Independent States and in the USA military expenses have greatly decreased. I am sure that this process will gradually embrace the whole world and that military industry will be peacefully incorporated into the international creative economies of the 21st century.

Now, the main question: what is the difference between the 20th and the 21st centuries when considering the development of science? One may state the following. The main motivation for the development of science and its applications in the 20th century was vigorous growth of production with a tendency toward intensity and the preservation of resources (some countries lagged behind for various reasons) and the wish to produce more in a better and cheaper way. The development strategy of science in the 21st century will change as we approach the border where technology is limited not only by economy of resources and raw materials, but by problems linked with global changes in the biosphere – the habitat of man, which forms a defense against negative, natural, and anthropogenic factors which are close to the critical point already. All this stipulates a new direction for scientific investigations and more close political and economic collaboration between the countries of our planet. Of course, the wish to discover and understand something new was, is, and will be an irresistible stimulus for scientists, no matter whether the discovery will be of practical use to people or whether it will open new paths for science and cognition.

Obviously, the foundation of a culture common to all mankind will begin in the coming century. This process has already been started by the UNO and international links in the fields of economics, linguistics, philosophy, history, the arts, music, and so on, create worldwide cultural space. This process is being considerably enhanced by growing international economic and political integration, which leads to an increase in trust between nations: although Western and Eastern countries, especially, have a long way to go yet. However, the process has started and one should strengthen and protect it. Economics and culture become components of global processes on the planet.

Now, let us look at fundamental science, which will support mankind's care for its habitat. First of all, let us consider informatics. We are approaching the epoch of global computerization, when computer technology will penetrate all spheres of human activity from high-level science to completely automatic production. Supercomputers and personal computers will increase their performance and link together forming a gigantic global computing network on the planet based on new technologies, software, and knowledge bases. Computers using optical and molecular elements will be created and widely used. This will allow performance to be increased by many orders. However, this is not all. Computers with parallel processors have a broad area of potential: a start in this direction has already been made - by the creation of transputers, special systems of high performance. These technical advances will form a base for creating data and knowledge bases on economic processes, technology, the environment, and the trends in its changes on a local and global scale. Satellites will provide all the necessary original information.

One may postulate that considerable development will occur over the next decades of methods of analysis and solution of non-linear problems in mechanics, physics, thermophysics, hydrodynamics (including geophysics), and other important fundamental directions in science. In our generation non-linear problems were investigated, opening new roads in science. Studies of non-linear problems have already led to outstanding achievements: the discovery of strange attractors, the formation of dynamic chaos and stable coherent structures on its background, the phenomenon of synchronizing frequencies, and others. These phenomena proved to be in some sense typical for different fields of physics, chemistry, and biology. These studies have already boosted the understanding of the appearance of turbulence, which is so important for hydrodynamics, physics, and hydrophysics. It is a problem that humanity has thought about for more than 100 years.

The theory of adjoint equations will play an exclusive role in the solution of biospheric, geophysical, and ecological problems. It will help to solve the problems of minimizing the stresses caused by the ecological and biospheric perturbations which trouble society. The ways of constructing adjoint equations corresponding to non-linear processes in the atmosphere and in oceans are already defined by science. They allow the precalculation of the sensitivity of functionals of the problems linked to life-support for one or another region of the globe to perturbations of different kinds. This is one of the most important problems of the present.

We stand on the threshold of many discoveries in all fields of science and our task is to implement them, where possible, in modern technologies and in ways which support economic, ecological, social, and other programs. Through these programs people will appreciate the role and meaning of science in society.

Each field of science already has a huge potential of knowledge. Without doubt, the powerful progress of science will pass along the road of interdisciplinary links, which will provide unprecedented acceleration of those studies which are of principal importance to people's lives and to the planet itself. Of course, this will require a thorough reconstruction of education, which will become one of the fundamental links in such progress, since education in the 20th century was mainly directed toward narrow specialization.

The International Institute for Applied Systems Analysis may play an outstanding role in this integrating process.

PLENARY ADDRESS

Science and the Challenges of Environmental and Developmental Issues

G.O.P. Obasi

This conference will focus on the relations between environment and development, particularly on the challenges they pose to the present and future generations. For my part, I wish to address the particular linkage between environment and development, on one hand, and science and technology on the other.

Environment and Development

Today, humanity is very much aware that we live in a world that is poised on the threshold of a new epoch in which the survival of human existence, as well as that of other species on the planet, is threatened and endangered. Nations have to cope with many issues like droughts, desertification, flooding, natural disasters, depletion of the ozone layer, environmental degradation, and a possible climate change. There is increasingly disturbing evidence that man's activities are rapidly changing life-sustaining balances. We have gone beyond the point where sustainable use of the atmosphere as a highly mobile dump for man's waste is possible without serious consequences. We are now more aware of possible implications of the stratospheric ozone layer depletion, a looming major change in climate, and the concomitant projected sea level rise. Furthermore, we are more conscious that failure to protect the environment can lead to the degradation of the natural resources base necessary for continuing development.

In an effort to maintain the quality of the environment and achieve environmentally sound and sustainable development, we need to address the protection of the atmosphere, land resources, including forests, freshwater resources, oceans, seas, and coastal areas, conservation of biological diversity, environmentally sound management of biotechnology and hazardous wastes, prevention of illegal traffic in toxic products and wastes, and improvement in quality of life and human health. We must take these into account as environmental concerns which also have to be considered in relation to the socioeconomic development efforts of many countries.

In this connection, basic changes will be needed if we are to move toward nationally and globally sustainable development. Among others, in the industrially developed countries, there will be a need to construct economic systems that use resources more sparingly and efficiently, as well as minimizing waste discharge. In developing countries, it will be necessary to ensure socioeconomic growth to meet the rising expectations of growing populations and to ensure that this takes place in a manner that will minimize resource depletion and environmental stress.

Indeed, issues relating to poverty, increasing world population, concerns for special groups like women, children, and indigenous people, financial resources, and technology transfer are important considerations for environmentally sound and sustainable development. It is estimated that about 125 billion US dollars per year is the order of magnitude of the international financial resources required for the full implementation of the Agenda 21 programs proposed by the United Nations Conference on Environment and Development (UNCED). It may be noted that this is 70 billion US dollars more than the annual official development assistance currently being made available by industrialized countries. Nonetheless, this is less than 1% of the gross national product of principal donor countries. Financial mechanisms, such as those similar to the Global Environment Facility, will have to be established to meet the requirements. These will also be necessary to facilitate technology transfer to developing countries in conditions favorable to those countries. In addition, suitable institutional structures should be in place to ensure the implementation of the necessary activities.

Role of Science

In citing these various areas of concern, it is readily apparent that these issues relating to environment and development are very much linked to science and technology. The current issues relating to environment and development can be seen as requiring responses to questions which are within the domain of science and technology. For instance, the increased consciousness of the subject of global environmental changes has been brought about through the painstaking efforts of many men and women of science.

Humanity has now reached the stage, both in terms of the magnitude of the earth's population and the sheer weight of its activities, where it makes its impact felt on the planetary scale. Demonstrating the existence of such global environmental impacts, for example, the depletion of the ozone layer or increase in the global greenhouse effect of the atmosphere, and showing their connections to specific human activities, has been a major achievement of environmental sciences in the last decades. As a result of the work of the world's meteorologists, hydrologists, oceanographers, and ecologists, a new awareness has been created of the role of man and the influence of human actions on a finite planet; one whose limited resources are being subjected to escalating demands from an increasing population. New scientific insight, on a broader scale than ever before, has given humanity a new perception of the limits of the resources of our planet, a recognition of the interdependence of all men on the planet, and an awareness of the necessity of achieving a sustainable balance between man's needs and nature's resources.

Through a better understanding of the earth's system, there is an improved estimate of the carrying capacity of the planet and its resilience under the many stresses placed upon it by human activities. While much more still needs to be done, science has nonetheless provided some ways of achieving a better understanding through the use of improved networks of ground observations and through the application of effective and efficient modern tools such as remote sensing instruments, modeling capabilities, and high-speed computers. Science has helped to show the link between the basic significance of this earth system as a life-support system and appropriate strategies for development that ensure the earth's sustainability or continued functioning.

Indeed, global change is upon us. The momentum of human economic development and population pressure on natural resources is such that we must expect significant alterations of the hitherto relatively stable global environment. Science and technology can provide effective warning of a number of future events, consisting of information on the magnitude of expected variations, the timing of these variations, and the geographical patterns of change. In a nutshell: how much, when, and where?

Scientific knowledge could and should be applied to support the goals of sustainable development through scientific assessment of current conditions and future possibilities. Science should be seen as an essential component in the search for viable, sustainable development pathways. For instance, science is playing an increasing role in improving the efficiency of utilization of renewable and non-renewable resources. Hence, developing countries need not follow the high energy consumption path previously taken by industrialized countries as they seek an improvement in their socioeconomic standing.

In the context of the present discussion, it can therefore be said that a primary role of science is to enable better formulation and selection of environment and development policies in the decision-making process.

Science and Society

The increasing concern related to environment and development provides an opportunity to recall the mutual and synergistic relationship between science and society. On the one hand, science (and technology) contributes to the development of society. In turn, society must nurture the development of science if it is to contribute to society's advancement.

J.D. Bernal, a famous crystallographer, wrote extensively on the relationship between science and society. In his treatise on *The Social Foundations of Science* (Bernal, 1969), Bernal perceived "science as an integral part of both the material and economic life of our time and of the ideas which guide and inspire it." He also spoke of science in terms of "its application both to the satisfaction of human needs and to the processes of productive industry through which in modern society those needs can be satisfied." Furthermore, he considered science to be "the chief agent of economic and social change, and latterly, as a sure, concise and direct motive of social change itself." The analysis of the social transformation which had taken place in history led him to the view that we are witnessing, in the 20th century, a renewed "scientific transformation of society". This can be seen through achievements such as in the fields of energy, industry, communication, medical science, and agriculture, which are just part of what we now understand as representing some of the most essential changes of our time. Indeed, the particular example of the development of and ever expanding use of computers and satellites demonstrates clearly the pervasiveness of science and technology's contribution to human activities. A number of those human activities are closely linked to the issues of environment and development.

Support for Science

Given the symbiotic relationship between science and society, there is a need for society, in turn, to provide the necessary support to enable science to play its role with respect to the challenges of environmental and developmental issues. In this connection, four areas in particular should be addressed. These are:

- Strengthening the scientific basis for sustainable development.
- Enhancing scientific understanding.
- Improving long-term scientific assessment.
- Building up scientific capacity.

The four areas were identified following the International Conference on an Agenda of Science for Environment and Development into the 21st Century (ASCEND 21), which was held in Vienna in November 1991 and organized by the International Council of Scientific Unions (ICSU) in cooperation with the Third World Academy of Sciences (TWAS).

Let us consider each of these four areas in turn. Strengthening the scientific basis for sustainable development will imply, among other things, the need to strengthen the capabilities of monitoring the biosphere to enable countries, especially developing ones, to be masters of their environment. For example, on the climatic side, the national Meteorological and Hydrological Services would need to be strengthened. As agriculture is the primary economic activity of many countries, and since much of the agricultural production is rainfed, the role of these services is crucial for taking advantage of climate as a resource. Furthermore, there will be a need to develop the capacity for installation, calibration, and maintenance of necessary equipment, as well as for gathering, processing, and exchanging the acquired data. Such data will serve multi-sectorial purposes, including agriculture, water resources, land use, forestry, conservation, and management of the ecosystem.

The second area, enhancing scientific understanding, implies that full use of data and information needs to be made by undertaking appropriate research, especially research directed toward applications for improved and sustained productivity. Numerous research areas could be identified, but each country, depending on its policies and needs, resources, and development plan, should be able to identify a set of priority research areas to address. In the agricultural sector, for instance, there will be a need to strengthen the link between research and the small farmer. In that sector, it is estimated that widespread application of scientific results and known technologies could expand productivity by over 50%.

Additionally, collaborative effort among various institutions within each country should be encouraged. This should also be the case among countries within the region, as well as with those elsewhere. The concept of associated agricultural research centers supported by the World Bank is a case already under consideration [Consultative Group on International Agricultural Research (CGIAR)]. Moreover, the impacts of research will be felt even more if the use of modern technology is also taken into consideration. For purposes of illustration, the significance of the use of satellites and computers will suffice.

With respect to the third area, improving long-term scientific assessment, it is clear that the knowledge acquired through data gathering, analysis, and research must be used to provide scientific assessments. Such scientific assessments and projections are required at the global, regional, and local levels. The scientific assessments pertinent to the global warming issue which are provided by the WMO/UNEP Intergovernmental Panel on Climate Change (IPCC) are examples of how scientific assessments can provide a basis for policy formulation and decision making. It is recognized that much more still needs to be done, particularly to reduce the uncertainties in the timing, magnitude, and regional patterns of climate change. It is important that assessments should be able to provide a basis for mapping out manageable development pathways within the environmental and socioeconomic carrying capacity of each region.

Regarding the fourth area, building scientific capacity, it is clear that this is especially important for developing countries. Activities in support of this area should provide education, training, and facilities for local research and development, as well as improving access to relevant information for scientists and decision makers.

The scientific activities required can only be successfully pursued if the required human resources, suitably trained and well motivated, are available. Any development program should ensure that manpower development is an identified priority. High priority must therefore be placed on investments in people to provide the means of reaching long-term sustainable development. The quality of scientific and technical staff development programs needs to be improved and the resources input should be increased.

Concluding Remarks

It is clear that the environmental and developmental issues before us are complex and interconnected. These interlinkages between the various issues have to be seriously considered. A major task, then, is to understand the complex interacting processes. Such understanding will serve as a basis for the better formulation and selection of appropriate policies, decisions, and actions.

In view of the interdisciplinary nature of the challenges relating to environment and development, it will be necessary to have an integrated, interdisciplinary, and systems approach to these challenges. Individual branches of science cannot treat the problems in isolation from other branches, as was done classically. For instance, atmospheric concerns cannot be dealt with only in terms of physics, chemistry, and mathematics, but will also need to consider biological processes, among others. Moreover, the atmosphere also has to be studied in the light of its interaction with the hydrosphere, cryosphere, biosphere, and geosphere. Hence, I believe that there should be an increasing emphasis on interdisciplinary undertakings at national, regional, and international levels.

I am aware that global investigations are not without difficulties. They require the development and use of sophisticated observing systems and techniques (for example, satellites), as well as information management and system simulation capabilities using powerful computers. These are in addition to the worldwide implementation of more conventional operational observation networks. As industrialized countries more readily have the resources and technical capabilities to undertake the monitoring of the planetary environment, they should take the lead and provide support so that the necessary information and benefit can be provided for all.

At the same time, it is important to increasingly enhance the capability of developing countries so that they can participate more fully in and benefit from the relevant scientific and technical programs. I therefore wish to stress the importance of evolving a network of regional, specialized centers in the developing world. Countries with similar interests and requirements can come together to jointly address these areas of concern. Such centers may serve to trigger the growth of expertise that is essential to our efforts to meet the challenges of environmental and developmental issues. Certainly, the provision of financial and other resources will be needed to realize these centers.

In addition, it is also important that the public in general are aware and informed of these challenges we now face together. It is necessary to ensure that there is widespread dissemination of the relevant scientific information. Scientists must not limit themselves to their journals but must work with non-scientists, such as those in the media, to promote the dissemination of information, analyses, and assessments at the grass-root level. Non-governmental organizations (NGOs) have been increasingly active in this respect. Special groups, such as women and children, should be particularly targeted.

I believe that these proposals form part of what should be included in the considerations of appropriate science policies and programs. I am sure that this conference will identify others needed to meet the challenges. For my part, and on behalf of the World Meteorological Organization, I can only reaffirm our commitment to ensuring that the scientific disciplines in which the WMO is engaged continue to be in the service of humankind.

Indeed, many challenges lie ahead; but with great resolve and armed with the tools that science and technology can provide, we can turn these challenges into opportunities for advancement toward a better quality of life for all of us on earth.

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PART I

What is Sustainability?

CHAPTER 1

Sustainability and Technology

Harvey Brooks

Introduction

The concept of sustainable development popularized by the Brundtland Commission (WCED, 1987) represented a breakthrough for public understanding of the fact that economic development and protection of the environment are not necessarily in conflict with each other. However, there is still a challenge inherent in how to translate this concept into operational criteria for the choice of development strategies and for the selection and adoption of new technologies to support these strategies in a real world ecological, social, economic, political, and cultural context. Some progress has been made in the environmental and resource sphere through the concept of adaptive management (Orians, 1990), but the difficulties are multiplied when the enormous number of possible social, economic, technical, and cultural variables are brought into the picture, especially in the light of their complex interactions and interdependencies. The difficulty is further compounded by the intrusion of a wide diversity of implicit or explicit (and frequently conflicting) value perspectives from both the developed and developing worlds. This diversity of value perspectives, derived from different life experiences and cultural histories, tends to undermine the possibility of any consensus on the criteria for sustainability in most concrete decisions even though, as Robert Solow observes, sustainability is something that it is hard to be against in general (Solow, 1991).

The term has a ring of scientific objectivity which can serve to legitimize various personal or group political agendas, overt or hidden, and thus has a rhetorical value in public discussions which is not matched by its operational usefulness.

For the concept of sustainability in the process of development to be operationally useful it must be more than just an expression of social values or political preferences disguised in scientific language. Ideally it should be defined so that one could specify a set of measurable criteria such that individuals and groups with widely differing values, political preferences, or assumptions about human nature could agree whether the criteria are being met in a concrete development program. In other words a meaningful description of a sustainable development process should, as far as possible, take the form of "public knowledge" as defined by John Ziman in his book of that title (Ziman, 1968).

In such a view there may be many different scenarios that would meet the criteria for sustainability but would differ from each other in other dimensions, including many that correspond to different values and political preferences. In this sense sustainability implies an important constraint on choices of development strategies, but does not compel any single strategy. For example, different degrees of equity, democratic governance, protection of pristine environments, degrees of urbanization or other human settlement patterns, reliance on sophisticated technology, or levels of material amenity could all be compatible with sustainability but would correspond to vastly different political and social values.

The discussion of sustainability is further complicated by use of the terms "sustainable development" and "environmentally sound technology" as though they were equivalent and could be applied interchangeably. All forms of economic progress involve environmental modification, some much more than others. Some of this will be deterioration, and hence economic progress and increased living standards often entail some compromise between economic and environmental goals, but just how much compromise is necessary is a matter for intense debate. Also, to an extent not always appreciated, there are many positive synergies between economic growth and environmental quality, especially in the developing world. An important development strategy may be to exploit these synergies and give priority to development projects or programs that simultaneously improve the environment (World Bank, 1992).

What is sustainable and preferred from a strictly environmental point of view may not be sustainable from a broader sociotechnical perspective that considers factors other than environment. On the other hand, what is sustainable from the broadest perspective, including one that assigns high priority to environmental values, may nevertheless still not satisfy the criteria for environmental "soundness" preferred by groups which favor minimum alteration of the "pristine" environment as a kind of moral imperative. To put the matter another way, many different levels of environmental protection and preservation may satisfy criteria of sustainability while still not being acceptable to influential constituencies in society, perhaps even a majority in some instances.

Definitions of Sustainability

One definition of sustainability is that "world conservation strategy should include management of the use of a resource so it can meet human demands of the present generation without decreasing opportunities for future generations" (National Research Council, 1991). Solow puts it that our obligation is to conduct ourselves so that we leave to the future the option of choosing to be at least as well off as we are, not in every detail but in some overall sense. This is inevitably somewhat judgmental, because future generations may have different values and expectations than we do, nor can we foresee today the technologies or other social capacities that may be available to future generations. In fact Solow (1991) emphasizes that leaving the world as we found it *in detail* is not only not possible but not even desirable. We must take into account not only the resources we use up but also the resources and human capacities we leave behind, including especially newly created physical infrastructure, new knowledge, and new capacity for technological and social innovation. This includes the broad notion of "social capital" as a development of social organization, social norms, social networks, and social trust or sense of community that enhance the capacity of ever larger social groups for "coordinated action" (Putnam, 1992; North, 1990).

Thus sustainable strategies do not necessarily always entail sacrificing the present for the sake of the future. To the extent that we can use a given quantity of presently known natural resources to create more wealth and more useful knowledge with which to find, extract, and use future resources more efficiently, or to substitute more abundant raw materials for those presently used in human artifacts, we have not only not sacrificed the present for the future, but we may have actually enhanced future options beyond what would have existed in the absence of this draft on present resources. Thus, whether this is so is a quantitative question that demands a sophisticated analysis relating to the particular circumstances. The demands of intergenerational equity do not automatically imply a zero-sum game with our descendants. If they did, the problem of sustainable development would be politically much more intractable than I think it is. Knowledge, especially knowledge that becomes fully internalized in the skills and capacities of many people widely spread around the world, and is passed on to the next generation, is a resource which is not depleted by more intensive utilization for human benefit today.

Solow also argues that investment in environmental protection today contributes to sustainability only if it comes at the expense of current consumption, but not necessarily if it comes at the expense of investment that adds to future capacity (Solow, 1991). Quantitatively, this depends on the future return from the particular investment that is foregone in favor of more environmental protection. But there is also some ambiguity in what we define as investment and what we define as "current consumption". For example, helping the poor today could, under some circumstances, be regarded as an investment in "social capital" to the extent that creating greater equity will build a greater sense of community and result in greater participation in society in the future and hence increased capacity for "coordinated action" by the entire human community. However, it is probable that even investments in "equity" will be relatively unproductive unless they are targeted at enabling the poor and disenfranchised to become more productive, not just compensating them for their inability to consume today – which may even undermine their sense of self worth or of membership in a community with shared purposes. Too little may be known about what makes for community to decide with certainty whether this is investment or consumption.

Thus a sustainable policy for the selection and deployment of technologies is one that forecloses as few future options as possible, compatible with any given level of present benefit. If there are several possible alternative choices today, each leading to roughly equivalent near-term benefits, then the most sustainable choice is the one that leaves open the greatest range of future choices. A minimum requirement is that today's actions do not paint the world into a corner from which retreat is either impossible or unaffordably expensive at some time in the future. As we will indicate later, however, this criterion is often more subtle and difficult to apply in practice than it sounds.

It follows from the above that it is necessary to foresee sufficiently clearly where present trends and choices are leading and what alternative endpoints to those projected might be possible through the adoption and exploitation of new and emerging technologies or policy innovations, taking into account costs, local capacities to assimilate such innovations, and the overall time scales required for them to have any effect. This is the essential function of technology assessment (TA) which must be an integral part of the evolution of any development strategy (Brooks, 1973a). However, even this poses a dilemma in that insistence on too much foresight prior to action could result in the paralysis of policy because of the fear of making mistakes (Hirschman, 1967).

In the literature on sustainable development, as explained in a recent report of the National Academy of Sciences (National Research Council, 1990), two poles of opinion can be distinguished, one of which the authors label "conservationist" and the other "possibilist". Conservationist thinking is based on an image of nature "in its original state perturbed by sporadic human blundering" – a "better safe than sorry" prescription. The possibilists, on the other hand, have embraced an image of space-ship earth as the creation and responsibility of enlightened long-term engineering. In this perspective, mistakes are possible, even likely, but with sufficient alertness and wisdom may be detected in time and remedied before their consequences have become irreversible. Reality probably lies intermediate between these two images, but the possibilist view represents a more reasonable working hypothesis for discussing the concept of sustainability in the context of the requirements of a sustainable strategy for world development and the closing of the rich–poor gap. Such closure is almost certainly essential for long-run *social* sustainability in an increasingly closely interlinked global society, and it is, quite properly, the preoccupation of virtually all international organizations, including the UN system.

Scientific uncertainty, both in measurement of the current state of the biosphere and in inferring future trends from current data and understanding of fundamental processes going on therein, is a major impediment to operationalizing the concept of sustainable development in both managed and natural ecosystems – not to mention sociotechnical systems more broadly. In some cases the insurance premium (measured in terms of foregone development, especially in poor countries) that may have to be paid in order to fully hedge against current technical uncertainties may be so high as to be politically or economically unrealistic. Whether or not this premium is worth paying depends on the projected cost of reversing the future consequences of current decisions if the premium is not paid. To some degree the seriousness of this dilemma may be diminished by more intensive measurement, monitoring, and research, which reduce the range of uncertainty earlier (Carpenter, 1990). It is in this sense that research and new knowledge is one of the best insurance premiums, and one whose value tends to be systematically underestimated even in the light of today's large investments in research and development (Brooks, 1990).

Some Propositions About the Sustainability Concept

The preceding attempt to define the concept of sustainability more precisely leads to the following set of propositions.

- Sustainability has to be defined as a *sociotechnical* attribute of a development strategy. It cannot be formulated in purely ecological terms. It is an attribute of a system of which man, nature, and technology are inseparable parts (Brooks, 1980a, 1980b).
- The usefulness of the sustainability concept depends on the degree to which it can be formulated in a relatively value-neutral way, susceptible to specifiable measurements, whether physical, social, or economic. This does *not* mean that values are unimportant. But, since sustainability is about the future, and we cannot foresee the values of our descendants, we need to focus primarily on those attributes of policy that determine man's survival as a species. Sustainability is primarily about a viable society rather than a desirable society, though obviously the two cannot be completely separated. In that sense the purpose of the concept is to reduce the debate to a more scientific discussion rather than a trans-scientific discussion, using the distinction originally proposed by Weinberg (Weinberg, 1972; Brooks, 1972). A future scenario which is not sustainable will eventually collapse (i.e., will not be viable) because of its inherent contradictions, but there will be many future scenarios that are sustainable by the "scientific" definition that might not be acceptable to the majority of people as judged from the perspective of contemporary political and social values.

  This concept of a value-free definition may be illustrated by considering various future scenarios in the light of different population projections. Higher future world populations require much more economic growth and much more intensive deployment of new technologies than lower future world populations to be sustainable. Yet, within certain limits, either population projection might be designed to be sustainable by the human survival criteria we have in mind. On the other hand, if we add other social values to our criteria, the lower population projection might be considered much more desirable by most people.
- Sustainability is an evolutionary concept, confined to finite epochs in time and, at least historically, to limited geographical regions. It is strongly governed by previous developmental

history and the historical cultural context. It is unlikely that there is any technological and developmental scenario, even a "no-growth" or "steady state" one (Brooks, 1973b; Wad and Radnor, 1984), that could be sustained indefinitely, since the context is constantly changing for both external reasons and reasons internal to the system itself. In part this is because of the large number of variables involved that are constantly changing on different time and space scales.

- Rates of change in demography, social structure, and technology are important determinants of sustainability. What may be sustainable in a slowly changing system may become unsustainable under conditions of more rapid change; the rate of change relative to generational turnover is an important parameter. In the contemporary world "problematique", population growth and migration are especially critical variables because, for the present at least, they seem to be the least amenable to deliberate social manipulation. But that may not always be so, in part because the present situation is so without historical precedent that it has not yet had a chance to be incorporated into the perceptions and values of adults that have grown up in a different world.

  Given a sufficiently long time for adjustment, the world could probably adapt to a much larger total population than we can envision at present, though it might not be a very attractive place to live in if judged by contemporary values, and it would probably be much more of a man-made or "artificial" world than we can even imagine today (Marchetti, 1978).

  Over human history on the planet there have been remarkable upward steps in the maximum population which the earth could sustain. These have taken place as a result of changes in technology and in the pattern of human settlements and interactions made possible by technology. There is some reason to believe that similar steps up in the future might be possible, but they would require changes at least as radical as the transition from hunter–gatherer societies to irrigated agricultural civilizations or the transition from agricultural civilization to an industrial, urbanized one that took place in Europe, Japan, and America in the last 300 years. However, the transitions in population and settlement patterns in these cases occurred much more gradually than the changes that have occurred in the last 50 years and will have to occur in the next 50 if human societies are to remain viable. Hence the rate of adaptation required is completely without precedent in human history. The 20th century is the first in which such radical changes in all the parameters of human existence have taken place within the life span of a single generation. In the past such changes have sometimes taken place locally in such short periods, but they have never extended over whole continents or the whole world so fast. It is thus the simultaneous magnitude of the changes both in time and space that presents such an unprecedented challenge to human adaptation capacities.

However, human capacity for adaptation has also grown at an unprecedented speed, especially in respect of the power of science and technology, and it has probably never grown faster than it is growing today. The population of scientists and engineers and other professionals continues to grow at two to three times the rate of the population as a whole or even of the total world labor force. This is even, perhaps especially, true in most of the large developing countries. But science and technology are not only the principal instruments of human adaptation to a changing environment; they are also one of the principal causes of that environmental change, either through the direct effects of their applications, or through their indirect effects in enabling much more rapid population growth and more rapid and extensive systemic interactions through communications and transportation. It is not clear – or at least not agreed upon – which side of the adaptation equation science and technology should be weighed in on. Furthermore, they are not the only tools required for human adaptation. To be effective their results must be rapidly diffused and assimilated, and must actually become manifest in "social learning" of unprecedented scale and depth. This is dependent on many factors outside the system of science and technology itself. All of this means we cannot be sure whether the ratio of adaptability to the need for adaptation is increasing or decreasing, nor of how it will change in the future. Nor do we have a clear idea of the societal parameters that affect this ratio.

- Activities that are non-sustainable in isolation may become sustainable within a larger system, but, conversely, activities that appear to be locally sustainable because of the flow of resources and other inputs from outside can become unsustainable when viewed within a larger system or on a longer time scale; only detailed understanding of the system in conjunction with all its interactions and the evolution of the external systems with which it interacts can determine whether a local activity or policy is truly sustainable.

  As an example, a developed country might grow rapidly on the basis of either renewable or non-renewable resources imported from a developing country based on an unsustainable system of exploitation. In this case the "slow variables" that affect the sustainability of the given system may be external to the system itself as ordinarily defined. Some would argue that the rapid economic development of Europe and Japan on the basis of cheap imported Middle East oil after World War II was an example of unsustainability of the type envisioned here. The "slow variables" are political evolution in the countries that control the oil and, ultimately, the depletion of the resource itself. Deforestation in the tropics is an example of unsustainability exported from one region to another in this sense, at least insofar as it is the result of exports to developed countries.

  In ancient history many local civilizations rose and declined because of the exhaustion of local rich resources of metals or forests which they were not able to replace by imports or which they did not know how to exploit sustainably. On the other hand, Britain, which at one time produced over 50% of the world's copper, was able to make the transition to substitute sources without serious dislocation (National Research Council, 1969). Thus the sustainability of a development strategy is something that has to be examined on several time and space scales, taking into account the transferability of resources and organizational capacities of different societies in both time and space. Account must be taken not only of present capacities, but of those which could be acquired by various times in the future, or accessed through international cooperation.

Conversely, many primitive cultures have existed for centuries, or even millenia, in excellent harmony with their environments, only to break down when they came into contact with more "advanced" societies. This may not be only because the advanced societies consciously "imposed" inappropriate values on the primitive ones, but also because there is probably no way in which primitive cultures in today's world can be sufficiently insulated from external influences over the long term.

These and other examples show that the criteria for sustainability have ultimately to be defined with respect to a spatially heterogeneous system consisting of clusters of interacting, spatially related systems, not necessarily in geographic proximity with each other. In fact, as the work of Holling (Holling *et al.*, 1974; Holling, 1986) and Forman (1989) has shown, even spatially heterogeneous ecosystems can be sustainable over the long run when their homogeneous components are unsustainable. Heterogeneity itself is an important consideration in maintaining the resilience of ecosystems because different elements of the heterogeneous system act as reservoirs for regeneration of other elements. Ultimately, of course, sustainability must be considered on a global scale. Because the flow of resources between different elements in a spatially heterogeneous system often depends on political and economic relations between the people that inhabit these elements, the separation of the sociopolitical and ecological aspects of sustainability becomes more and more inappropriate. The behavior of people is inseparable from the other elements of the total system.

- In development planning, increased attention is being given to local ecological folk wisdom which has accumulated gradually over generations on a semi-empirical basis. There is an increasing realization that the complexity of ecosystems is such that we tend to overestimate our ability to predict the effect of interventions, and that therefore a higher burden of proof should probably be imposed on those interventions that are undertaken than has been customary in the past (Brooks, 1976). For this reason, as well as for reasons of political legitimacy, it is important to involve many potential "stakeholders" in dialogues leading up to development planning decisions. In this sense, such dialogues may be regarded as an integral part of the concept of sustainability in development. However, the folk wisdom must eventually be reinterpreted in scientific terms if it is to be utilized with confidence. Folk wisdom may be vulnerable to internal contradictions which develop as a result of changes in the circumstances in which it originally evolved; scientific understanding is required to anticipate this. Furthermore, many of the potential stakeholders cannot be represented in these dialogues – e.g., the large fraction of the population of developing countries that consists of young children that will live in an entirely different world from that of their parents, as well as unborn generations in all countries affected by today's planning decisions.

- The concept of non-renewable or exhaustible resources is probably not a meaningful or useful one in defining sustainability because of the constant evolution of the resource base through improvements in the technology of exploration, extraction, recycling, and substitution. Resources are not finite or fixed because their availability for human use depends on technology, culture, and historical antecedents. So-called renewable resources are thus likely to pose a greater challenge to sustainability than so-called non-renewable resources (Brooks, 1982a). The ratio of non-renewable resource consumption to output has been steadily declining in the developed countries, and this trend is likely to accelerate as the application of information technology increases the value added to materials in manufacturing (Ayres, 1987). The economic value of national output consists to an increasing degree of the value added by information and human ingenuity relative to the value of the material and energy inputs.

  It is not too difficult to envision a day when more and more of the materials of civilization will be synthesized from cheap and abundant raw materials essentially by the use of materials engineering on a submicroscopic or molecular scale (Ashby, 1979). The modern integrated circuit is probably a harbinger of things to come in an increasing number of applications, in the field of structures and mechanical systems as well as in microelectronics (Ayres, 1986; Brooks, 1982a).

In fact, the resources that seem to be most in jeopardy (water, forests, clean air, the assimilative capacity of various components of the environment) are almost always ones whose scarcity is not reflected in market prices, while resources whose future supply is assured are those for which scarcity is reflected in market prices so that substitution, technical progress, and structural change are motivated by adequate economic incentives. In fact, whether or not the prices are right, reflecting the full private and social costs of availability may be a more appropriate way to categorize resources than whether they are renewable or non-renewable. This is not to imply that the application of market principles can automatically solve all problems of sustainability, even if, in theory, all "externalities" could be fully internalized in market prices, but it does suggest that market principles should be the first place to look for solutions, with other policies to be invoked only after they have been carefully considered and found wanting.

The case of rural deforestation in the tropics is a good example of where the complex interaction between social structure and the ecological systems in which it is embedded can lead to unsustainability in a sociotechnical sense. It has been shown, for example, that deforestation in many developing countries has been mostly the consequence of misguided public policies which, though often undertaken by government for purposes that were thought socially beneficial, have had the unintended result of fostering excessive private exploitation which would have been uneconomic, even in the short term, in a free market (Repetto and Gillis, 1988). In almost every case direct or indirect government subsidies have distorted prices in such a way as to yield windfall profits to some entrepreneur even though the project would be uneconomic if prices had reflected all costs even without considering externalities.

The Ubiquitous Role of Surprise

The tendency in assessing sustainability is to try to extrapolate smoothly from existing trends. However, this is more often than not thwarted by the appearance of surprises and discontinuities that are unanticipated and sometimes impossible to anticipate even in principle. A recent example is the rapid appearance of the "ozone hole" over the Antarctic, which was unforeseen despite several years of prior large-scale observational and theoretical research on the mechanisms of stratospheric ozone depletion. Other examples of surprise are the wide gyrations in the availability and price of oil (for political rather than technical or economic reasons), the serious accidents at Chernobyl and Bhopal, and the rapid rise and evolution of the AIDS epidemic. None of these events were inevitable, though the fact that the system was susceptible to them in the sense that they were "accidents waiting to happen" could have been, and often was, anticipated. But this probability was such that they could have happened earlier or later within an interval measurable in decades, and the consequences might have been quite different, depending on the exact timing. One of the major challenges to policy analysis for sustainable development is how to factor the possibility of such surprises into planning without becoming paralyzed by hedging against every conceivable contingency. The dilemma is that the probability of any single such event is extremely small and the time of its occurrence almost totally unpredictable within a long time interval (Brooks, 1986). Advances in knowledge and their rapid and wide diffusion constitute one of the best forms of insurance against such surprises, as illustrated by the role of molecular biology in dealing with the AIDS epidemic or the role of 20 years of prior advances in atmospheric chemistry enabling rapid understanding of the physical mechanisms involved in the formation of the ozone hole, making it possible to prove that it was indeed of anthropogenic origin and not a natural fluctuation.

Similarly, in the case of the build-up of greenhouse gases in the atmosphere, the most important consideration may ultimately prove not to be the slow climatic warming predicted by the global circulation models (GCMs), but rather sudden discontinuous shifts from one climatic regime to another. Indeed, the whole subject of climate change is replete with possibilities for such surprises. Sudden release of the West Antarctic ice sheet with rapid sea level rise was one such surprise that was considered credible a few years ago, but has since been downgraded. Undoubtedly there will be others, some of which might be less easily discredited. Positive feedback effects between warming and rapid release of methane, a much more powerful greenhouse gas than CO_2, are still not fully explored, for example.

The only way that surprises of this type could be avoided would be to prevent the further accumulation of greenhouse gases in the atmosphere altogether. Yet present indications are that such a strategy would require reduction of, for example, CO_2 emissions to something like 20% of their present level, something that would be prohibitively costly to world development at any time in the near future. The present negotiations regarding "stabilization" of emissions at their present levels, or modest reductions like 20%, are aimed only at slowing the growth of greenhouse phenomena so as to buy more time for corrective action at some distant time in the future, such as the early part of the 22nd century. But the effectiveness of such a strategy of postponement is predicated on the absence of any surprises of the sort suggested above. There is actually no truly long-term strategy even under discussion that would truly "stabilize" the slowly changing composition of the atmosphere.

Fortunately, surprises can be both positive and negative in their potential ramifications. Examples of positive surprises are serendipitous scientific discoveries and technological breakthroughs such as the discovery of recombinant DNA techniques and the resultant development of biotechnology, or the rapid evaporation of the military confrontation of the superpowers in the Cold War. Such events can present unexpected opportunities for development, and contingency planning must be as much concerned with positioning ourselves to exploit new opportunities as to deal with unpleasant surprises.

The importance of surprise as an integral part of IIASA modeling was first introduced into IIASA research in connection with the "Sustainable Development of the Biosphere Program" largely under the influence of Holling, who was Director at the time that the program was initiated. A number of efforts were made to develop various "surprise" scenarios for the evolution of world society and to assess their implications for policy (Svedin and Aniansson, 1986). But I think it fair to say that relatively little progress has been made in developing a systematic approach to the exploration of possible surprises and developing a methodology for incorporating them into planning. One of the difficulties is that there are so many possibilities, any one of which has too low a probability to warrant much effort in the way of contingency planning. Still there is a need for a more coherent and sustained effort to invent possible mechanisms for surprises in an area like global climate change, then launch an effort involving both theory and field observations aimed at ruling them out as possibilities, and a parallel effort to invent possible strategies for dealing with them if only for the purpose of estimating the costs of avoiding or mitigating them.

Environmental Priorities

The initial response to the identification of environmental problems in the industrial countries, especially the United States, was to deal with them one by one, characterizing the problem, and then to design a response without much consideration of the collateral consequences of this response, including its costs to the economy. This was quite reasonable as long as the total number of problems was small, and the response to any one problem could be considered as a minor perturbation of the existing sociotechnical system. Problems were non-interacting and could be considered as independent of each other to a good approximation. As long as response costs were small, the response did not have to be very efficient or cost-effective. Furthermore, there was a tendency to think in terms of the particular medium in which a pollution problem first manifested itself, and solutions which merely moved the pollution to a different medium were often accepted uncritically.

However, as the number of problems identified has proliferated, both the assumption of independence and the neglect of inter-medium transfers became less acceptable. In addition it became necessary to consider not only the cumulative effect of environmental threats – each minor by itself – but also the possible synergistic interactions among threats. On the response side, the cumulative economic costs of large numbers of relatively inexpensive regulations also came to be of concern.

An important consequence of the cumulative costs was that it became necessary to consider the efficiency or cost-effectiveness of alternative responses, not just the effectiveness. A second consequence was that it became increasingly impractical to deal with all problems at once; it became necessary to develop some scheme for ranking problems in terms of their effect on people, usually according to some combination of the number of people potentially affected and the levels of health or other damage experienced by those affected. If this were not done explicitly, it was done implicitly simply through neglect of all but the squeakiest wheels, devoting the most attention to the most publicized problems with little scientific analysis or assessment of their real impacts on people.

One recent manifestation of a greater political interest in priorities has been the recent popularity of market-based mechanisms for environmental protection. Advocated by economists for nearly 30 years, such ideas have received little serious attention by politicians or administrators until recently, when market-like provisions were included in the 1990 amendments to the US Clean Air Act. The principal argument in favor of such provisions has been that they lead to devolution of decisions to numerous individual private sector actors where market forces lead to the automatic concentration of environmental improvement efforts on those sites and activities where the greatest environmental benefit per unit of expenditure can be achieved. Thus markets provide semi-automatic priority-setting mechanisms which are believed to be more objective than attempts to regulate thousands of individual polluters. My point here is not to advocate market mechanisms as a panacea, but merely to relate their suddenly emerging political popularity to the emerging pressures for priority setting in the interest of greater cost-effectiveness of environmental controls as their number inevitably proliferates (Stavins, 1991; Hahn and Stavins, 1991).

This effort to set priorities among environmental problems according to the magnitude of their effects on people and to consider cost-effectiveness of regulations has encountered considerable resistance. Indeed many people in the industrialized countries resist the very notion of priorities, believing that all environmental degradation is bad and should not be accepted by society, once its existence is known or even suspected. Polluting the environment should be prohibited, and cost should not be a legitimate consideration. Indeed, the implicit attitude toward pollution was similar to that toward disease. Any action to cure the problem that provided some benefit was justified irrespective of its benefit–cost ratio. Just as the cure for disease was to be paid for by third parties through insurance, a good fraction of the public was led to believe that the cost of environmental clean-up would be paid for by business, not fully recognizing that most of the costs would eventually be passed through to consumers since they were imposed on all producers and thereby removed from competition in the marketplace.

Within the last few years the EPA and other agencies in the USA have begun systematic efforts to rank environmental and health and safety threats according to the harm they do to people or ecosystems, including the number of people affected. This has revealed that there are wide disparities among expenditures on mitigating environmental problems and the ranking of these problems according to the severity of their effects on people as assessed by experts. The reasons for these differences are complex. Some arise from ignorance, but many arise from different implicit value judgments of experts and laymen. One of the most dramatic examples of this is the relative ranking of the dangers of nuclear power by laymen and experts. More generally, laymen tend to attach much greater relative weight to improbable catastrophic or dramatic events as compared with more probable statistical events, but this is not the only difference.

The effort to rank environmental threats in relation to world environment and development policy has recently been taken up by the World Bank (World Bank, 1992). It argues that local problems affecting very large numbers of people – such as unavailability of uncontaminated drinking water, lack of sanitation, indoor air pollution from cooking fires, and atmospheric particulate loading or lead contamination – are much more serious than things that are absorbing a lot more world resources and political attention such as greenhouse warming, stratospheric ozone depletion, acid rain, photochemical smog, or hazardous chemical waste sites. Of course, these threats affect different groups of people, and it could be argued that environmental amenities are like goods for private consumption: rich countries can afford more of them and more expensive ones than poor countries. Indeed, that is the way much of the Third World looks upon environmental discussions.

The international debate over what constitutes equitable sharing of responsibility for the mitigation of greenhouse warming appears to have reached an impasse in part because the problem is being negotiated among nations sensitive to issues of sovereignty. An aspect of this negotiation that needs greater attention is the idea of optimizing the reduction of greenhouse gas (GHG) emissions on a global basis, i.e., securing the largest possible GHG emission reduction worldwide per unit of world expenditure. From this perspective negotiating GHG reduction targets on a country by country basis may be regarded as a wasteful use of the total resources available for this purpose. There are several reasons for this. First, the advanced countries already produce less CO_2 emissions per unit of GDP than the less advanced ones, and for this reason the marginal cost of additional reductions is likely to be higher in the advanced countries than in the LDCs. It thus may be more efficient in many instances to shift investments that would have been made in GHG reduction in an advanced country to an LDC where the same amount of money would generate much more "bang for the buck". The argument for this is further strengthened when one considers that many polluting and resource consuming activities are growing faster in LDCs than in advanced countries, even with present rates of growth in LDCs which are less than desirable if the rich–poor gap is ever to be narrowed. For example, electric power production in LDCs is growing on average two to three times as rapidly as in developed counties, a situation further exacerbated by the fact that electricity generation and distribution is generally heavily subsidized and therefore underpriced to the consumer in LDCs (World Bank, 1992).

All this means that LDCs have more opportunity to adopt the most advanced, energy efficient and low emission technology on both the supply and demand sides. Thus, if a utility in a developed country could demonstrate that the money it would have invested in reducing its GHG emissions could buy more GHG reduction in a developing country by transfer of technology to and financing of the construction of the most modern equipment in that developing country, it should have the option of choosing that alternative and being "forgiven" by its own government for a certain amount of its own GHG emissions. This would work especially well if the host developed country had a carbon tax on which its utility could receive a credit for the investment it made in a developing country. In this way there could be an efficiency rationale for the transfer of capital and technology to LDCs which would not depend either on the altruism of firms or governments in the developed countries or on coercion. In effect developed countries could reduce their GHG emissions less than required by treaty targets in exchange for a greater contribution to GHG emission reduction in a rapidly growing LDC. This is a complex idea that would have to be worked out in much more detail than that which I have sketched here, but it illustrates a possible way of unlocking the political gridlock between North and South in present negotiations by restructuring the self-interest of private entities in the North. This kind of global optimization might be something in which it would be especially appropriate for IIASA to specialize.

Time Discounting and Sustainable Development

The question of priorities cannot be separated from the question of time discounting because, in estimating the costs and benefits of various proposed policies, the benefits are realized only after some time has elapsed since the costs were incurred. In particular, the benefits of investment in clean drinking water and sanitation are realized quite soon, whereas the benefits of actions to slow down global warming may not be fully realized for generations. In such circumstances, the conventional way of comparing benefits and costs at different times is to use time discounting, reducing all benefits and costs to "discounted present value" at a given time by applying a single assumed "social discount rate". Quite apart from choosing the correct discount rate, which involves many implicit value judgments, the application of discounting to very long term problems such as global warming or stratospheric ozone depletion assigns a weight to problems which span generations which makes the discounted present value of the benefits of their mitigation negligibly small. Thus, as has been pointed out by Rothenberg (1992), traditional benefit–cost analysis with a single discount rate through time could never be used to justify major action now to forestall global warming or many other long-term problems because, with weights declining exponentially with distance into the future, shorter term costs would always dominate the equation under any reasonable assumptions. Only if the future impact were absolutely irreversible would such effects be even worthy of consideration today, but, in view of the unpredictability of advances in science and technology in such a long period, such absolute irreversibility could not be assumed. Thus, in practice, the use of social discounting seems to be simply a prescription for present inaction in dealing with any sufficiently long-term problem. Yet this is a conclusion that seems to violate common sense intuition.

The difficulty is compounded by the huge scientific uncertainty which attends the estimation of benefits so far in the future, especially if they span more than a single generation. One way of estimating the benefit might be to estimate the cost of mitigating the damage either by progressive preventive actions (e.g., gradually reducing emissions through conversion to non-fossil energy sources) or by adaptive measures (e.g., building sea walls to ward off flooding of low-lying areas, or developing and deploying a method of producing food in closed climate-insensitive environments). But both scientific and social uncertainties this far into the future would be so great that such estimates would be virtually worthless, not to mention all sorts of surprises, unpleasant and pleasant, likely to appear along the way. Such considerations might be used to argue for the universal superiority of adaptation over prevention because the cost of adaptation tends to be incurred much closer to the time when the damage is imminent and therefore suffers less from the weighting problem described above. Taking this position might involve the argument that, with the proliferation of new science and technology, much of it unpredictable, the estimated future costs of adaptation are much more likely to decrease than to increase over long periods of time. Of course, all sorts of value judgments are implicit in such a decision.

In dealing with this dilemma, Rothenberg suggests what amounts to an incremental approach in which the unit of analysis is a single generation and certain assumptions are made about intergenerational transactions only at the boundaries between successive generations. It is impossible to do justice to Rothenberg's very sophisticated analysis in this summary. I will only say that he proposes that the use of time discounting be restricted to a single generation at a time and that beyond the present generation the discount be thought of as a very slowly decreasing step function so that weights applied to costs and benefits beyond the present generation decline only very slowly. The essential normative feature of his proposal is that each generation should pass on to the next generation at least the same capacity to create welfare as it inherited from the previous generation. In this respect, the philosophy is very similar to that of Solow. I believe that an approach along the lines suggested by Rothenberg could be thought of as doing the same for a quasi-normative theory of intergenerational equity as John Rawls tried to do for intragenerational equity in his *Theory of Justice* (Rawls, 1971; Bell, 1972).

Solow (1991) also points out that there is an inherent competition between equity among existing people on earth and intergenerational equity. For example, by investing heavily today to forestall catastrophic greenhouse warming by the end of the 21st century, are we shortchanging today's poor for the benefit of unborn future generations? Also, to what extent can helping the poor today be regarded as an investment in "social capital" to facilitate a greater social capacity for "coordinated action" to deal with problems as they appear in the future? This also relates directly to what was said earlier about priorities for dealing with environmental and health problems that affect the largest number of people in the present.

New and Emerging Technologies

As far as the impact of technologies that need to be assessed for "soundness" is concerned, old technologies in long use are quite often more likely to present problems than new and emerging technologies (although much of the rhetoric surrounding global environmental problems implicitly ascribes them to technical progress). In many cases these new technologies may be environmentally less stressful than older technologies provided that they are appropriately deployed with appropriate social support systems. Since they are "emerging" by definition, so that large sunk costs have not yet been incurred, there is more opportunity to adapt the implementation of the technology and its supporting systems and institutions to avoid undesirable impacts. This is one potential advantage in principle available to developing countries, which need not be condemned to repeat all the costly environmental errors of the developed countries, since they are in a position to adopt the newer, less polluting technologies, which are not necessarily more expensive than the old ones.

Furthermore, one of the most important factors in technological impact is its scale of application. Many of the most serious adverse impacts of technology, both environmental and social, are related to scale of use, and one of the primary functions of technology assessment should be to estimate in advance the limits on scale of use that are compatible with sustainability, and to modify the subsequent evolution of the technology so as to moderate the growth of its impact with scale of use (Brooks, 1986). Two prime examples of this are automobile emissions and the use of chemical pesticides. A technology which is perfectly sound when used on a small scale or for a limited period of time until superior technologies become available may be unsound and unsustainable if used on a sufficiently large scale or over a sufficiently long period of time. In addition, a technology which is sound in one location may be unsound in another. One of the difficulties faced by developing countries such as China and India is that the scale of use of some technologies now being used in some developed countries, but being phased out, cannot possibly be accommodated sustainably on the same scale relative to population in the more populous developing countries – chemical pesticides and personal automotive transportation being two examples.

Application of the Concept of Sustainability to Biodiversity

As an example of one attempt to operationalize the concept of sustainability, we will take the issue of biodiversity. This is of particular interest because its loss seems absolutely irreversible in a way that applies to few other environmental changes that can be in principle reversed, albeit at a prohibitive, though finite, cost.

"What exactly constitutes biodiversity?" and what are the "grounds on which species and habitats should be protected, sustainably managed or re-created"? (Smith *et al.*, 1991). There is no authoritative forum in which this can be discussed. Timothy O'Riordan (1991) identifies four positions:

- Absolutist:
  "any further species loss is a crime against creation."
- Ecologist:
  "endangered species and habitats should be protected."
- Pragmatist:
  "some crude cost–benefit analysis at each stage of [prospective] further loss."
- Gaianist:
  "earth is a creative force that will eventually establish its own equilibrium of species mix, within which humans may become marginal."

Generalized pleas for the preservation of biodiversity are not helpful; there must be some priorities. All species are not equally valuable from the standpoint of possible future human benefit, but we have too little information on which to base choices. Each of the positions listed above constitutes a guideline for an implicit set of criteria for the preservation of biodiversity. The absolutist's position implies that the preservation of species should take precedence over every other consideration regardless of the impact on the present generation of human beings. This assumes that, in the absence of any reasonable basis for choice, we must preserve everything we can - an essentially infeasible prescription, in effect dictated by our massive ignorance of the potential resources of the biosphere.

The ecologist's position departs from the absolutist's position by trying to establish the danger of loss of a particular species as a criterion, but it makes no clear distinction in principle on the basis of potential usefulness to man or evolutionary position (such as priority of mammals over insects or insects over bacteria). Furthermore, it provides little guidance on how to deal with the high percentage of species that have never been identified or described. The best we can do is to preserve certain unique habitats known to be unusually rich in species or to harbor unique species.

The pragmatist's position bases priorities on usefuless to man, but in practice is necessarily opportunist, latching onto wild strains known to be related to domesticated crops.

The Gaianist's position is essentially fatalistic, implying that humans are not wise enough to decide; hence we should take no action except with the highest degree of certainty of its consequences, relying on the self-healing character of ecosystems. At its worst it could be a prescription for full steam ahead, relying on the self-healing wisdom of nature as an article of faith.

As the market for cultivated food and fiber crops expands, it becomes more important to maintain a larger genetic pool from which new traits can be selected as vulnerabilities of existing cultivars appear. There are several means of preserving gene pools:

- In localized natural ecosystems.
- In artificial ecosystems (e.g., nurseries).

- As seed, pollen, tissue or cell cultures, isolated from natural habitats, but from which desired organisms can be regenerated.
- Use of new biotechnology techniques to create, select, and preserve new genotypes not found in nature with desired properties.

Each of these modes can be equally effective if carried out wisely (National Research Council, 1991). However, it is important to preserve some genetic pools *in situ* in order that their genetic information can co-evolve with that of potentially threatening pathogens and pests in nature. The Nigel Smith *et al.* article gives many examples of resistant gene pools available from wild species in tropical forests that have been or can be used as countermeasures against pathogens and pests to which cultivated monocultures have become vulnerable (Smith *et al.*, 1991). Even this may be somewhat limited by the fact that crops often become commercially important in areas or environments far from the area or environment of origin where the variety was first domesticated from the wild.

Perhaps the most important policy action that can be taken with respect to biodiversity is to accelerate the rate at which the species content of relatively unexplored tropical ecosystems is assessed, with particular emphasis on their potential economic value. This is an example of the great importance of systematic knowledge as a prerequisite for policy action in the future. The type of knowledge needed is not necessarily at the frontiers of modern science, but may be rather routine and "boring" in the usual canons of research (Brooks, 1982b).

Conclusion

As we have indicated, sustainable development is a simple and powerful idea, which is nevertheless extremely difficult to apply unambiguously in concrete development decisions. Like many powerful ideas it has become a "buzzword" in the development literature, and is used by many different groups to express a wide diversity of value judgments, frequently disguised in seemingly value-neutral language, using the authority of science to enhance its political legitimacy.

One of its difficulties arises from the fact that, in its broadest sense, it applies to many different policy areas usually thought of separately and appealing to different constituencies. It involves technical, economic, social, environmental, and cultural factors which interact with each other in complex, and often unpredictable and surprising ways. Thus, it is a highly multi-disciplinary concept which it is very hard for any one expert analyst or policy maker to encompass in his or her thinking. Although intergenerational equity is central in the implementation of the concept of sustainability, it does not follow from this that achieving it is a zero-sum game between ourselves and our descendants. The reason it is not a zero-sum game is that it combines resources and environmental assimilative capacity which are finite with knowledge and human capacities which are enhanced rather than depleted by being used for human benefit. Knowledge wisely added to resources is the source of new wealth and human capacity, both individual and collective, which opens up new options and possibilities for the future, making economic and social growth potentially more and more compatible with sustainability as knowledge and its diffusion increase. Growth is in principle compatible with the finiteness of physical resources because of the possibility of steady and even accelerating "dematerialization" of GNP, in which growth of the knowledge-embodiment of resources substitutes for the volume of resources including the capacity of the environment to absorb residuals. However, we are only at the very earliest stages in such an evolution. Today, progress in "dematerialization", even in the most advanced economies, lags on average behind economic growth, and therefore must be accelerated, implying a diversion of a greater fraction of consumption to investment in research and development, human resource development, and the creation of new infrastructure. It is still too early to say how the race between environmental and resource deterioration and the growing human capacity for wise "coordinated action" will come out in the long run. In addition, of course, there are many more "intangible" resources such as access to pristine nature which are inherently finite but may be important for sustaining the human spirit. The larger the human population, the more these intangibles have to be substituted by synthetic images and artifacts, sharply circumscribing the realization of many values the present generation holds dear.

Summary

Sustainable development is an apparently simple and powerful concept, which is nevertheless extremely difficult to apply unambiguously to concrete development strategies and technology choices in a way that commands consensus among groups from widely different cultures and economic circumstances. This chapter sketches a definition of sustainability that is less dependent on value judgments, likely to be widely divergent, but accommodates a wide range of technology choices and development scenarios. It attempts to separate sustainability as a precondition for human survival in a material and social feasibility sense from desirability in a cultural or ethical sense, tied to contemporary values.

Sustainability as used here sets limits on, but does not fully define, viable policies in many separate areas. It involves technical, economic, social, environmental, demographic, and cultural factors which may interact with each other in complex and sometimes unexpected or counterintuitive ways. Thus it is a highly multi-disciplinary concept.

Although intergenerational equity is central to the implementation of the concept of sustainability, and sometimes comes into conflict with intragenerational equity, it does not follow that the search for sustainability need be a zero-sum game between ourselves and our descendents. This is so because it uses resources and environmental assimilative capacities which are limited in combination with knowledge and human capacities that can actually be enhanced by being shared and used for human benefit. Knowledge wisely imposed on material resources is the principal source of wealth and new human capabilities, both individual and collective, and this opens up new options for the future, making economic and social welfare growth potentially compatible with sustainability within wide limits of parameters. As long as knowledge embodied in material resources can be made to result in faster

"dematerialization" of GNP than overall growth of GNP, sustainable growth is theoretically possible.

Today we are only in the early stages of such dematerialization, and only in the advanced parts of the world, and it would have to be greatly accelerated by the application of new knowledge before sustainable growth could become a reality. The acceleration and consequent rate of investment in new technology required will depend strongly upon the size and growth of population.

Also discussed is the need for much sharper priorities in environmental protection and improvement, governed by a more objective assessment of actual effects on people and their capacities, and more focus is suggested in areas where environmental improvement and economic and social development are synergistic rather than in competition. There are many more such areas than is generally thought, especially in the Third World.

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PART II

Present Trends Need Cause Only Minor Concern

CHAPTER 2

Toward Dematerialization and Decarbonization

Tokio Kanoh

Introduction

Modern industrialized countries have achieved the prosperity they enjoy today by virtue of technological innovation, a market economy, and democracy. This prosperity has brought about extended longevity, increased incomes, shorter working hours, enhanced welfare, broader access to information, and everything that appears to be humankind's dreams come true one after another.

Today, people in developed countries are enjoying an unprecedented affluence, an affluence powered by energy derived mainly (80%) from hydrocarbons. How far advanced will this civilization and society become? Should it ever come to a halt, or even collapse, what will have gone wrong?

Amid this affluence of unprecedented proportions some phenomena have emerged that require attention:

1. Growing volumes of waste from both industry and households make it increasingly difficult for waste-disposal facilities to keep up.
   - Problems have already surfaced in New York City and Tokyo, exacerbated by the continued advance of office automation, a sharp increase in non-flammable, non-recyclable, disposable containers, and a tendency for consumers to use

durable goods as if they were consumables due to frequent model changes.

2. Urban pollution and traffic accidents are increasing.
   - There are 10,000 people killed in traffic accidents annually in Japan and more than 100,000 across the world.
3. Damage is being caused by acid rain.
   - The depletion of forests and contamination of lakes and swamps are advancing noticeably in Europe and North America.
4. Global warming is causing concern.
   - Concern is expressed about the effects of extraordinary climatic conditions on food production and ecology, rising sea levels eroding land area by immersion, etc.
5. There is increased disparity between North and South.
   - Industrialized countries together account for 4/5 of the global energy consumption while representing only 1/4 of the world's total population.
6. Social ills are spreading.
   - Drugs, crimes, AIDS, and homelessness are spreading in developed countries.

All these phenomena should serve as a warning against a self-destructive process set off by a civilization of disposables, characterized by mass production, mass consumption, and mass waste, resulting in depleted resources, environmental destruction, and moral corruption. Also, we should be reminded that it is a historical fact that the glorious civilizations of the past, whether Mesopotamian, Greek, or Roman, were all destroyed from within, not by an outside enemy.

From the above perspective, there are three tasks that we face in the field of energy:

1. To examine the substance of "affluence".
   - "Dematerialization" of affluence.
2. To cut off the chain linking energy to GNP.

- "Decoupling" of energy from GNP.

3. To maximize utilization of non-hydrocarbon natural resources and nuclear power generation as energy sources.
    - "Decarbonization" of energy.

"Dematerialization" of Affluence

From "material" to "event"; from "event" to "mind"

A sense of satisfaction develops in three stages: "having", "doing", and "being", which can also be interpreted as "material", "event", and "mind", respectively. The first stage relates typically to the desire to own durable consumer goods of one kind or another. In the developing stage of an economy, the purchase of automobiles, large-size household electrical appliances, and consumer electronics is a dream-come-true to fulfill people's sense of satisfaction. It is a stage where satisfaction lies in the ownership of hard-earned, precious items of durable goods.

In the second stage, personal ownership of durable items is not enough to provide satisfaction. People become more selective and personalized and seek "events" in which their selections are validated in public, as reflected in frequent model changes in durable goods, motor shows, Formula One Grand Prix races, home videos, communication antenna television (CATV), and ubiquitous expositions with ambiguous themes.

The third stage involves creativity, peace of mind, comfort, solidarity, and other such dematerialized areas of satisfaction. Take automobiles, for example. In the first stage, people want to own a car, but the kind does not matter much. The second stage finds consumers enjoying the speeds and distances they drive in a model of their choice. According to a public opinion poll regarding lifestyle and energy conducted by the Japanese Prime Minister's Office in July 1991, the personal ownership rate of automobiles has reached 82%, and, considering the broad range of choices offered in terms of types, models, colors, and services, Japanese consumers are way past the second stage.

The third stage finds users:

- Taking good care of their cars, driving safely, and developing a personal attachment to their own cars.
- Enjoying automotive benefits to the fullest extent with restraints guarding against the adverse effects on health of excessive reliance on vehicles.

Another example is air conditioners. At one time it was a dream appliance for every household. The same government survey shows that 66% of households are equipped with air conditioners. The number of units sold exceeds that of the number of households, which means more than one air conditioning unit for some households, possibly one for each room or individual use, ushering in a new era of "individualized use of electric power".

The first stage, in this case, is to be equipped with air conditioning and the second stage is to see it function properly to make summer cool and winter warm. The third stage, then, is to create a living environment in which natural forces are utilized to a maximum extent, with due attention paid to human health. In this stage, utilization of solar energy becomes popular, like passive solar use in houses which use deciduous trees as shades against the sun in summer and which take in sunlight and heat in winter as the trees shed their leaves. It also includes better insulation to protect against outside heat changes.

Excessive heating or cooling over and above outside temperatures is not good for health. The guidelines of 28 °C for summertime cooling and 20 °C heating in winter, originally set for the purpose of energy conservation, are taken to indicate the most comfortable room temperatures. In the above-cited government opinion survey, 61% of the pollees said that cooling in offices was too strong.

Proposals

- *Promote "eco-fashion".* In regions of high temperatures and high humidity in summertime, airy light clothes should be made standard and permitted on formal occasions. We can learn from Batik of Indonesia and Baron Tagalog of the Philippines in this respect. It would be more healthy and fashionable to be lightly clad in summer with additional clothing in winter. It also helps conserve energy and, for that matter, the global environment.

- *Prolong the use of durable goods.* Too-frequent model changes should be reconsidered, while repair parts inventory and service systems are set up to meet the needs of any model.
- *Build attractive infrastructure before indulging the convenience of private cars.* Instead of restricting the use of private cars or calling for restraint, urban and inter-city mass transit systems and city streets should be reconsidered to make them attractive enough for citizens to choose public transportation, walking, and bicycling over individual cars for commuting and traveling.
- *Improve school education.* Pupils must be taught in school to appreciate the values of things, as well as of energy, resources, and the environment, and to take good care of them. Such a subject should be made a required subject for entrance examinations and drivers' tests. In the same public opinion survey by the Japanese Prime Minister's Office, 82% agreed that the importance of energy should be taught in school.

Recycling

The two oil crises prompted industries to vigorously advance waste heat recovery or recycling. Examples of their successful efforts include coke dry quench (CDQ) for the blast furnace in iron-making and the heat-recovery boiler installation in the chemical industry. In the paper and pulp industry, utilization of black liquor, a waste product from the pulp-making process, and recycling of used paper are advanced.

However, the recycling of low-grade waste heat recovered from urban and industrial facilities is not yet fully developed, due partly to a decline in energy prices. In this respect, it is informative to discuss the district heating and cooling system using a heat pump which began operating in Japan recently. The system recovers unused waste heat and utilizes it as a power source for localized heating and cooling. *Table 2.1* lists some of the district heating and cooling systems using urban and industrial waste heat introduced by the Tokyo Electric Power Company.

Table **2.1.** Examples of district heating and cooling systems using waste heat.

Location	Area (ha)	Heat source	Supplier	Start-up date
Hikarigaoka	185	Garbage incineration	Tokyo Heat Supply Company	April 1983
Shinagawa Yashio	41	Garbage incineration	Tokyo Heat Supply Company	April 1983
Hibiya	5	Electric power substation	Tokyo Heat Energy Company	October 1987
Ginza 2, 3 chome	3	Electric power substation	Toden Real Estate Management Company	April 1984
Shibaura 4 chome	20	Electric power substation	Toden Real Estate Management Company	June 1987
Shinkawa	6	Electric power substation	Toden Real Estate Management Company	April 1988
Ginza 5, 6 chome	7	Public bath house	Toden Real Estate Management Company	August 1987
Kanda Surugadai	11	Electric power substation	Toden Real Estate Management Company	April 1988
Hakozaki	23	River water	Tokyo Electric Power Company	April 1989
Makuhari Hi-tech business	49	Sewage plant	Tokyo Electric Power Company	August 1991
Utsunomiya Chuo	11	Electric power substation	Tokyo Electric Power Company	February 1991
Hitachi	13	Manufacturing plant	Hitachi Thermal Energy Company	December 1989

Source: *Nikkei Shimbun* (1991).

Figure 2.1 is a schematic description of one such system which utilizes discharged water from the Hanamigawa Sewage Plant. Taking advantage of discharged water temperatures which are around 15 °C in winter and about 7 °C less than outdoor temperatures in summer, the system supplies heat for a high-tech business district encompassing some 50 ha. It is hoped that these types of systems will become more common as an integral part of the social system.

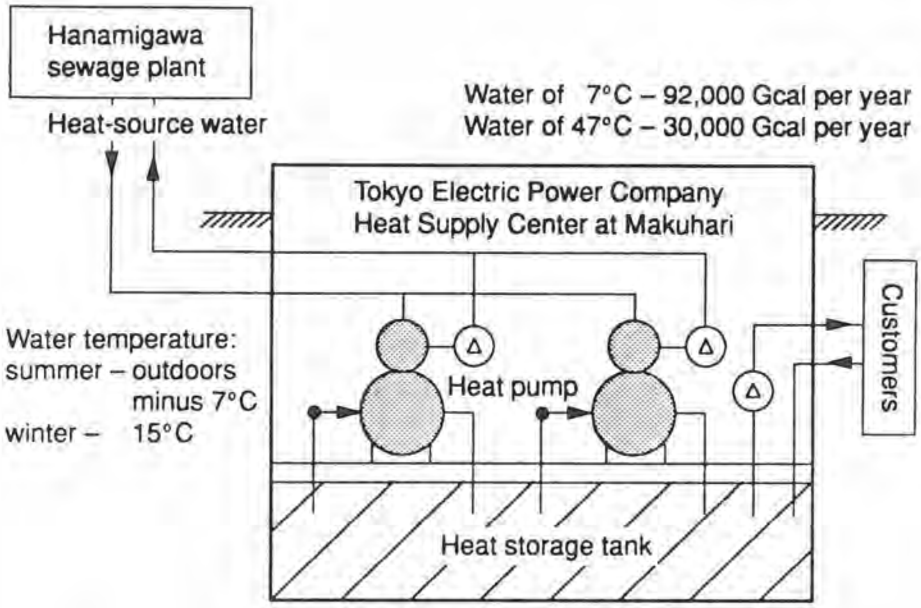
Proposals

- *Encourage recycling of returnable containers and aluminum cans.* Introduce a deposit system in which the retrieval costs of containers are added in advance to product prices to be refunded when they are turned in.
- *Promote recycling of urban and industrial waste heat and incorporate cascading utilization of heat into a social system.* Offer favored access to urban facilities and financial and tax credits as incentives.
- *Facilitate utilization of renewable natural energies.* Strengthen research, development, and demonstration to reduce costs.
- *Instead of "once through" or one use only of uranium as nuclear fuel, promote "nuclear fuel recycling" by reprocessing spent fuel.*

Structural changes in industry for resource conservation

The third aspect of dematerialization is structural change in industry. With the oil crises of the 1970s as a turning point, industrial countries started striving to change the traditional resource-consuming, energy-oriented structure of their economy and society. This trend was given further impetus by the revolutionary progress made in the fields of electronics/computers and optical fibers/digital communications.

Figure 2.2 shows structural changes as reflected in the demand patterns of large-volume power consumers ("volume power consumers" refers to industrial users contracted for 500kW or more of electric power for industrial use, including private power generation and consumption, but not for residential or commercial use).



Outline

Location:	Chiba City, Nakase 1-2 chome, Hibino 1-2 chome (48.9 ha)
Users:	Techno-Garden, IBM, Tokyo Marine, JASCO, Hotel Spring Building
Heat source:	Waste heat from office buildings, discharged water from sewage plant
Facilities:	Water heat source heat pump Cold heat – 20,500 refrigeration tons Warm heat – 56,500 Mcal per hour

Figure 2.1. District heating and cooling (DHC) system for Makuhari high-tech business district (Tokyo Electric Power Company).

Volume consumers used to be such raw-material-oriented, resource-consuming industries as steel-making, chemicals, aluminum refining, and cement up until the early 1970s. Starting in the latter half of the 1970s through the early 1980s, however, demands in the steel-making, chemical, and cement industries slowed

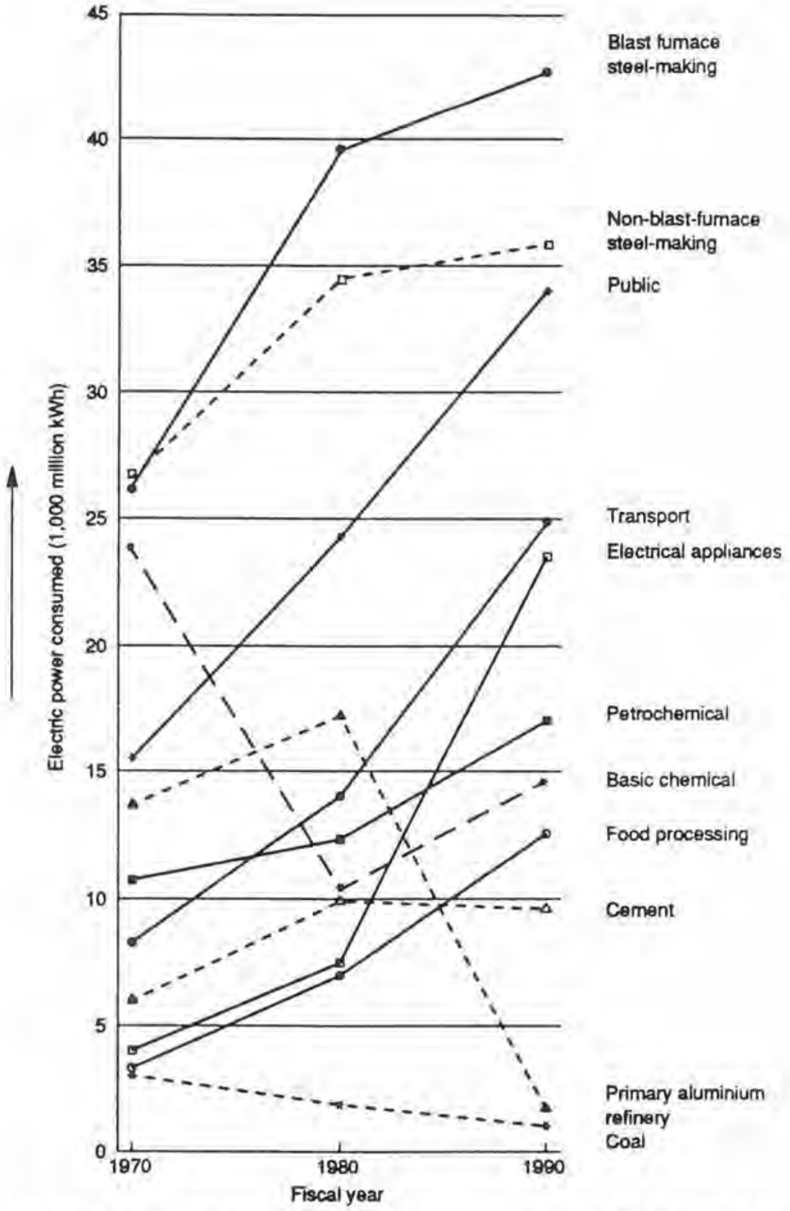


Figure 2.2. Volume electric power demands by use (total for Japan: includes private power generation). Source: *Electric Industry Data Book 1992* (1992). Note: 'Public' includes railways, communications, water supply and sewage, heat supply, city gas supply, etc. Partly estimated by the author.

down and primary aluminum refining was totally withdrawn, as can be seen from the figure.

On the other hand, less power-consuming sectors such as electrical equipment (semiconductors, facsimile machines, color TV sets, VTRs, air conditioners, etc.), transport (mainly automotive vehicles), and processing industries like food processing have been increasing their demands conspicuously. Particularly noteworthy is the movement, as seen in the figure, of the "public sector", tentatively compiled and so-named for the purpose of this analysis, which covers such services as railways, communications, water supply and sewage, heat supply, and city gas supply. Sharp rises in power demand in this sector, namely, from 15 TWh in 1970 to 24 TWh in 1980 and 35TWh in 1990, can be said to typically symbolize the tendency toward dematerialization.

Proposal

- *The market price mechanism must be respected.* A market economy optimizes the distribution of goods and flexibly adapts industrial structure to changes in the environment. It must be remembered that the rigidity of socialist bureaucracy led to the demise of the Soviet Union, once touted as a superpower.

Separation of Energy from GNP

Successful "decoupling"

From the 1960s to the early 1970s, energy demand grew in tandem with GNP in terms of growth rates. Decoupling, an attempt to cut off this linkage between energy and GNP, was successfully accomplished by the development and implementation of energy conservation technology, by the reduction of unit energy consumption by practising total quality control (TQC), and making structural changes in industries to accommodate energy conservation.

Figures 2.3 and *2.4* show trends in GNP with energy, oil, and electricity demands in OECD countries and Japan, respectively, as expressed in indices with 1973 as 100. These figures demonstrate the following three points.

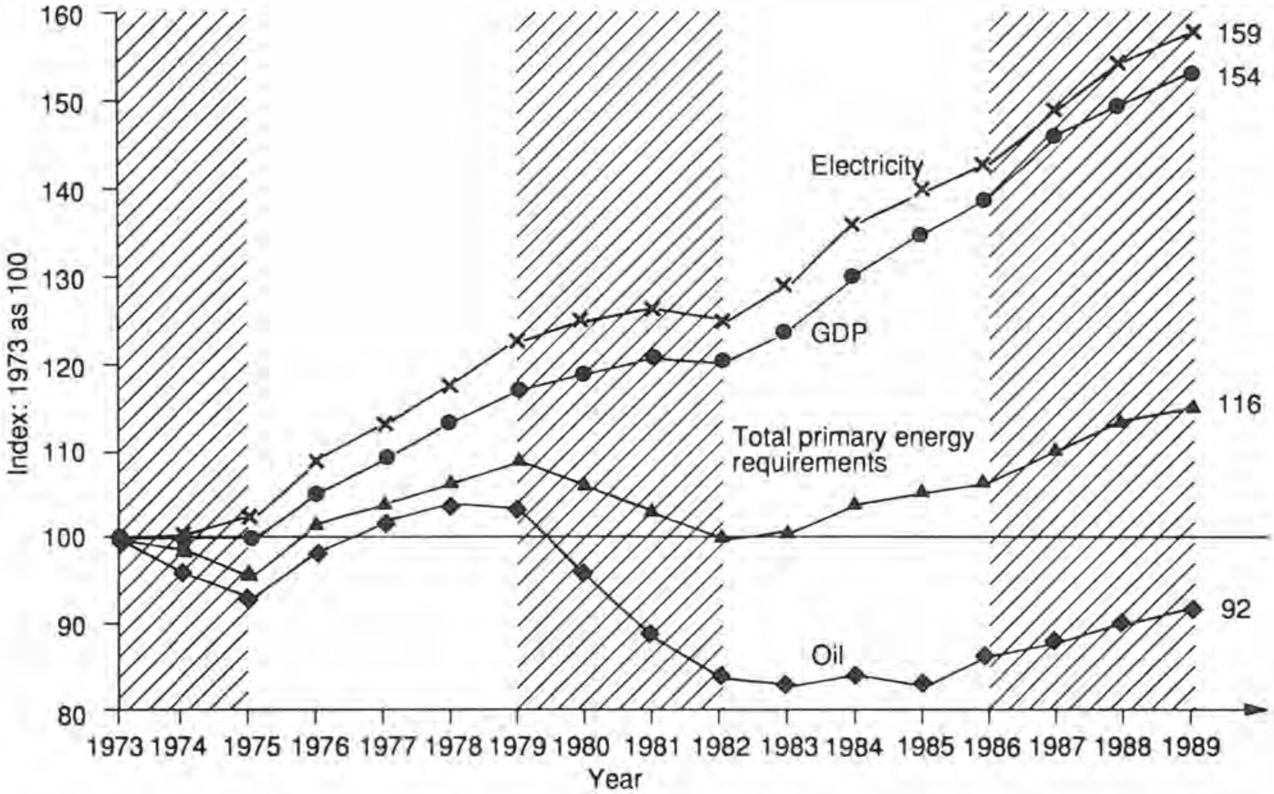


Figure 2.3. Economic growth and energy (OECD countries). Source: *Energy Balances of OECD Countries 1989–90* (1991).

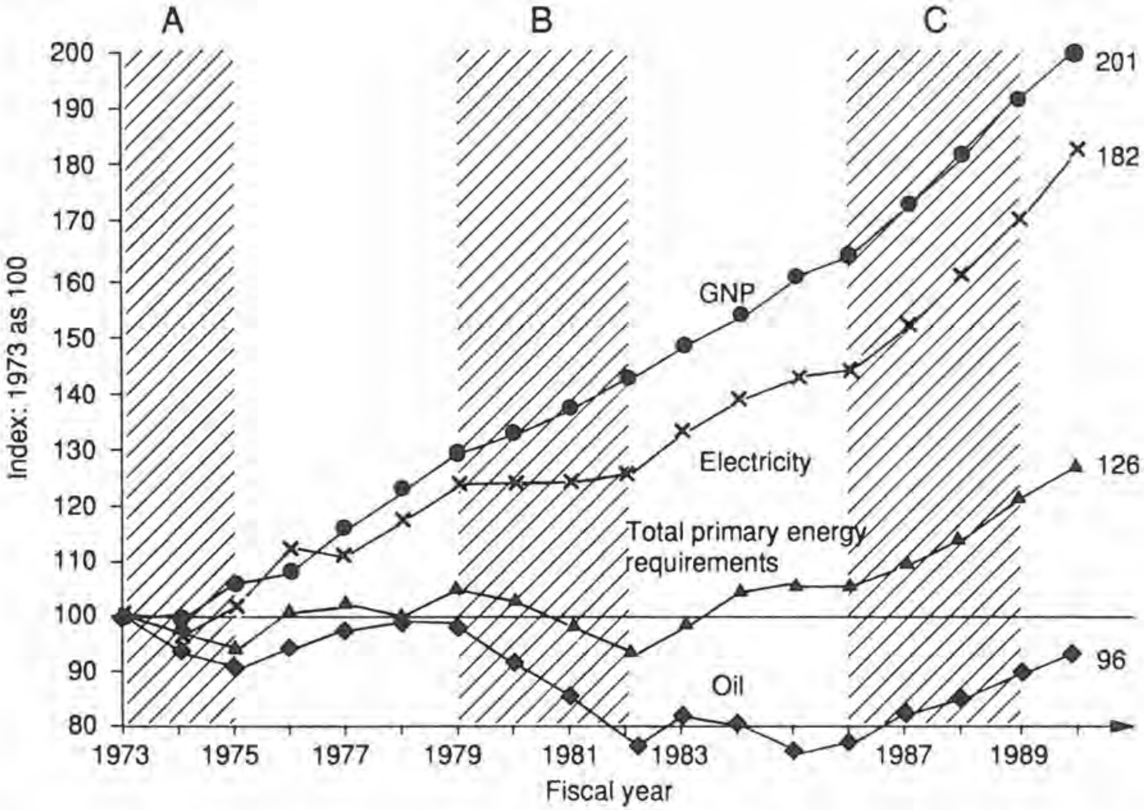


Figure 2.4. Economic growth and energy (Japan). Source: compiled from *Comprehensive Energy Statistics 1991* (1992).

1. GNP and energy/oil demand have been successfully decoupled.
   - In Japan, for example, the GNP in 1990 was double that of 1973, whereas energy demand increased by only 26% over the same period as a result of the vigorous pursuit of energy conservation. The demand for oil still remains below the 1973 level.
2. Electricity demand continues to rise steadily.
   - Electricity demand has been rising in a different way from energy as a whole, but in a similar manner to that of GNP. This is taken to reflect the fact that energy sources have shifted from oil and coal to electricity as processing-type industries such as semiconductors, robotics, facsimile machines, communication equipment, and cars became predominant on the industrial scene, and that the general tendency for emphasis on conservation, information, software, and amenities is pushing up electricity demand.
3. Prices have a significant effect.
   - Energy and oil demands are highly susceptible to price fluctuations. In *Figure 2.4*, during the first two periods of years shown by shading (sections A and B), prices went up, causing the demand to drop, whereas in a later period starting in 1986, as shown by shaded section C, when prices fell sharply, demand shot up. Otherwise, namely, when prices stabilized, demand started picking up gradually.

Figures 2.5 and *2.6* show international comparisons of energy consumption per US $1,000 of GNP, and similarly of carbon dioxide emissions, respectively, for 1989. The figures demonstrate that both energy consumption and CO_2 emissions are highest in the USA and Canada, both having severe climatic changes and a large land area where energy self-sufficiency rates are high and costs are relatively low.

In contrast, Japan is the lowest among major countries in both respects, with scarce resources and dense populations pushing up energy costs and leading to strict environmental standards. It should also be noted that the energy consumption rate of China is more than 10 times as high as that of Japan.

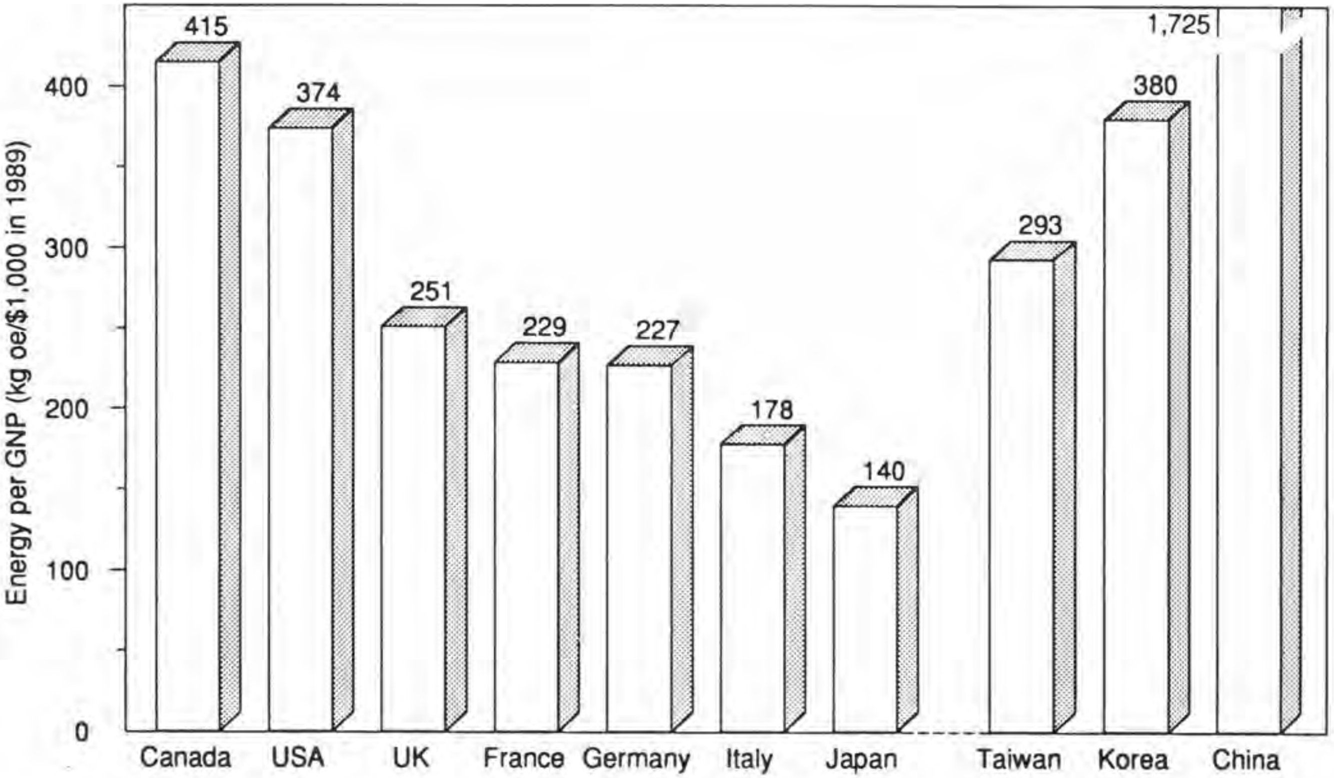


Figure 2.5. Energy per GNP (kg oe/$1,000 in 1989: where 'oe' is 'oil equivalent'). Source: compiled from *International Comparison Statistics 1991* (1992), *Energy Balances of OECD Countries 1989-90* (1991), and *Energy Statistics and Balances of Non-OECD Countries 1988-89* (1991).

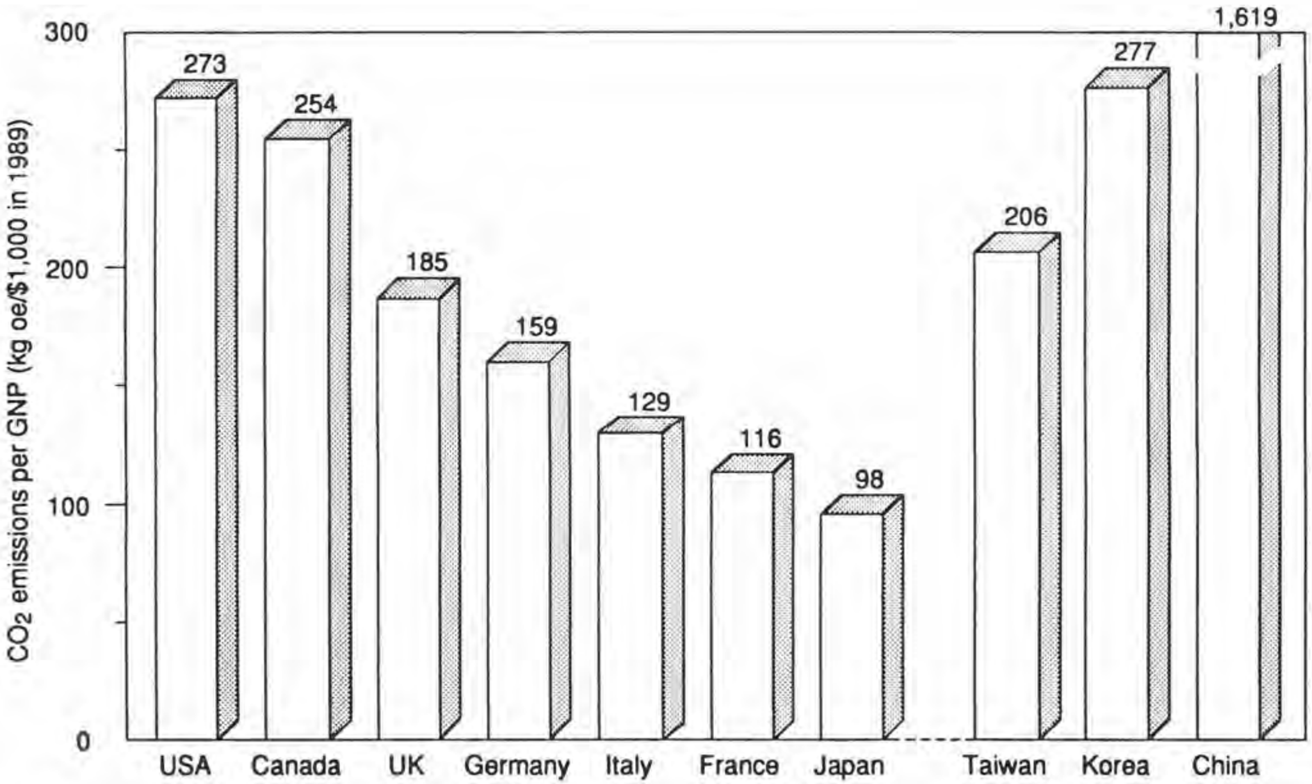


Figure 2.6. CO_2 emissions per GNP (kg oe/$1,000 in 1989). Source: compiled from *International Comparison Statistics 1991* (1992), *Energy Balances of OECD Countries 1989–90* (1991), and *Energy Statistics and Balances of Non-OECD Countries 1988–89* (1991).

Proposals

- *A market price mechanism is powerful.* Reflecting energy costs directly in product prices should promote energy conservation, fuel conversion on the demand side, and the development of alternative energies to replace oil.
- *Rising environmental standards are putting increasing pressure on industries.* However, once they are endorsed by public consensus, individual corporations are certain to do their best to meet them through whatever technological development and facility investment it may take.

Promotion of energy conservation by the industrial sector

In the preceding section it was stated that total energy demand has been successfully separated from GNP. Its impact, however, varies widely between sectors. *Figure 2.7* shows end-user energy demands over recent years in Japan, divided by sector. It is clear from this figure that the energy demand in the industrial sector remained constant at the 1973 level in 1990: this was only possible through all-out efforts to conserve energy on the part of individual businesses.

On the other hand, the demand increased by 63% in the private sector covering private homes, commercial users, offices, and office buildings, and 72% in the transportation sector which is accounted for mainly by automotive fuels. This is in stark contrast with the industrial sector. In the private and transportation sectors, the demand is expected to continue at relatively high rates, thus requiring appropriate measures to be taken.

Proposals

- *A review of the existing insulation standards for housing* with a view to taking measures to encourage better insulation.
- *Promote district heating and cooling systems* which effectively utilize the unused energy of waste heat.
- *Expand mass transit systems.*

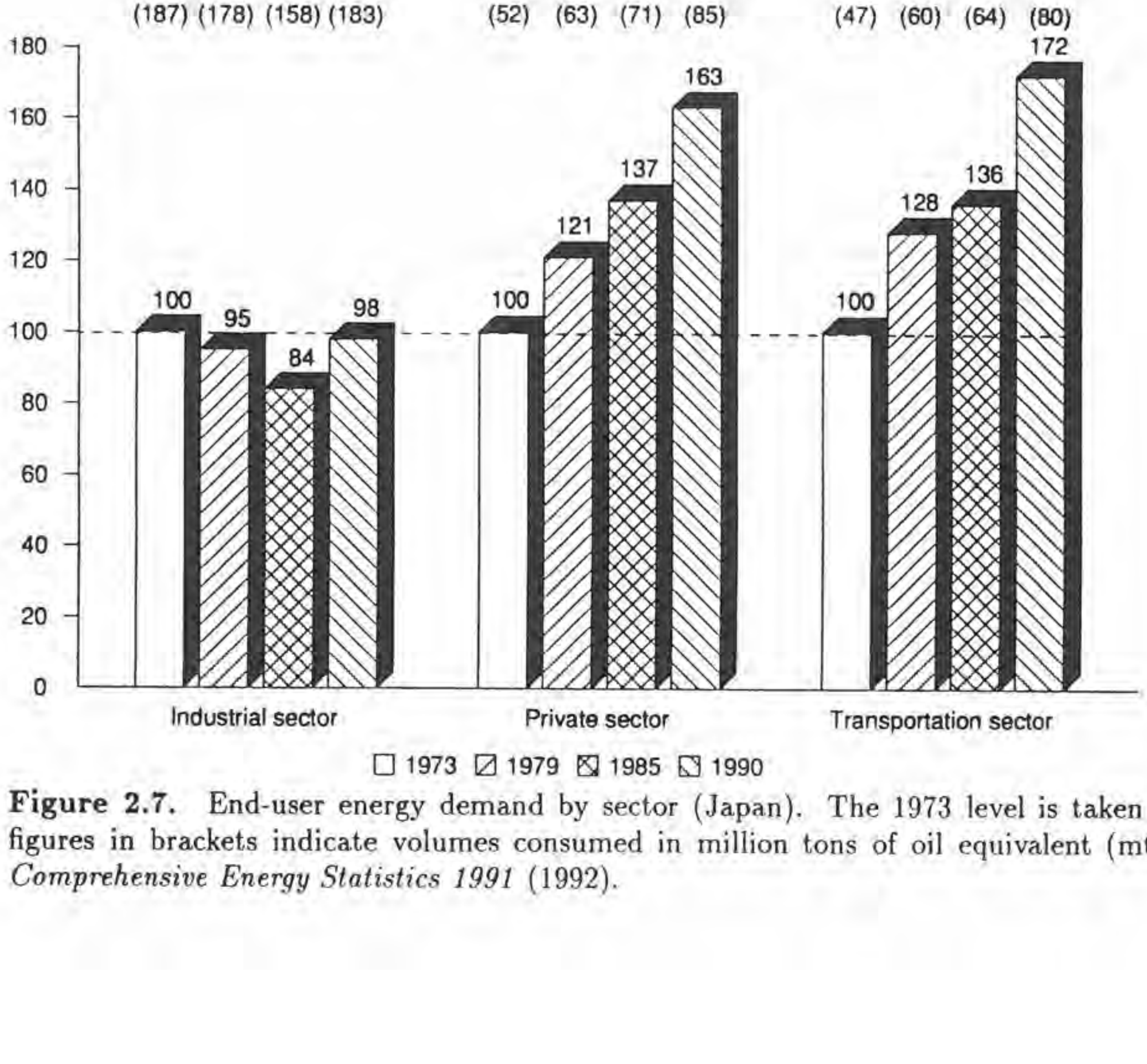


Figure 2.7. End-user energy demand by sector (Japan). The 1973 level is taken as 100. The figures in brackets indicate volumes consumed in million tons of oil equivalent (mtoe). Source: *Comprehensive Energy Statistics 1991* (1992).

- *Enhance the cost efficiency of automotive fuels and improve traffic control systems.*
- *Research, develop, and demonstrate alternative fuels for automobiles.*
- *Develop a multi-purpose heat pump of the household heat recovery type.*

Energy-conservation-oriented growth scenario

In *Figure 2.8*, relations between per capita GNP (x axis) and per capita energy requirement (y axis) are plotted out for 20 countries (regions). Most of the countries fall in the range of scenario 1 as defined by:

$$y = 0.25x \pm 1 \quad .$$

There are two exceptions to this. One is the US/Canada. Due to their geographical characteristics and the availability of abundant local resources, these two countries are positioned away from the standard scenario: they fit scenario 2 that applies to volume energy-consuming countries. The other exception is the former Soviet Union. This is largely because the per capita GNP as expressed in dollars has nose-dived due to the sharp depreciation of the ruble in the exchange rate.

Of the scenario 1 group countries, Sweden, Australia, New Zealand, and the UK are found along the line of scenario 1a, which means they are more energy consuming than the rest of the countries in that group, with Singapore, Taiwan, and Korea, or the newly industrialized economies (NIEs) collectively, "chasing" after them.

In the same group of scenario 1, Germany, France, Japan, and Italy follow the less energy-consuming scenario 1b, followed by Hong Kong.

Japan's positions are overlaid as they have changed over the years since 1960 (the GNP is given in terms of US dollars as of 1989). It shows Japan moving up the line of scenario 1b from 1960 until the first oil crisis, when it started swerving sharply to the right to change its course to energy-conservation-oriented scenario 3 where energy demand does not increase as the GNP grows.

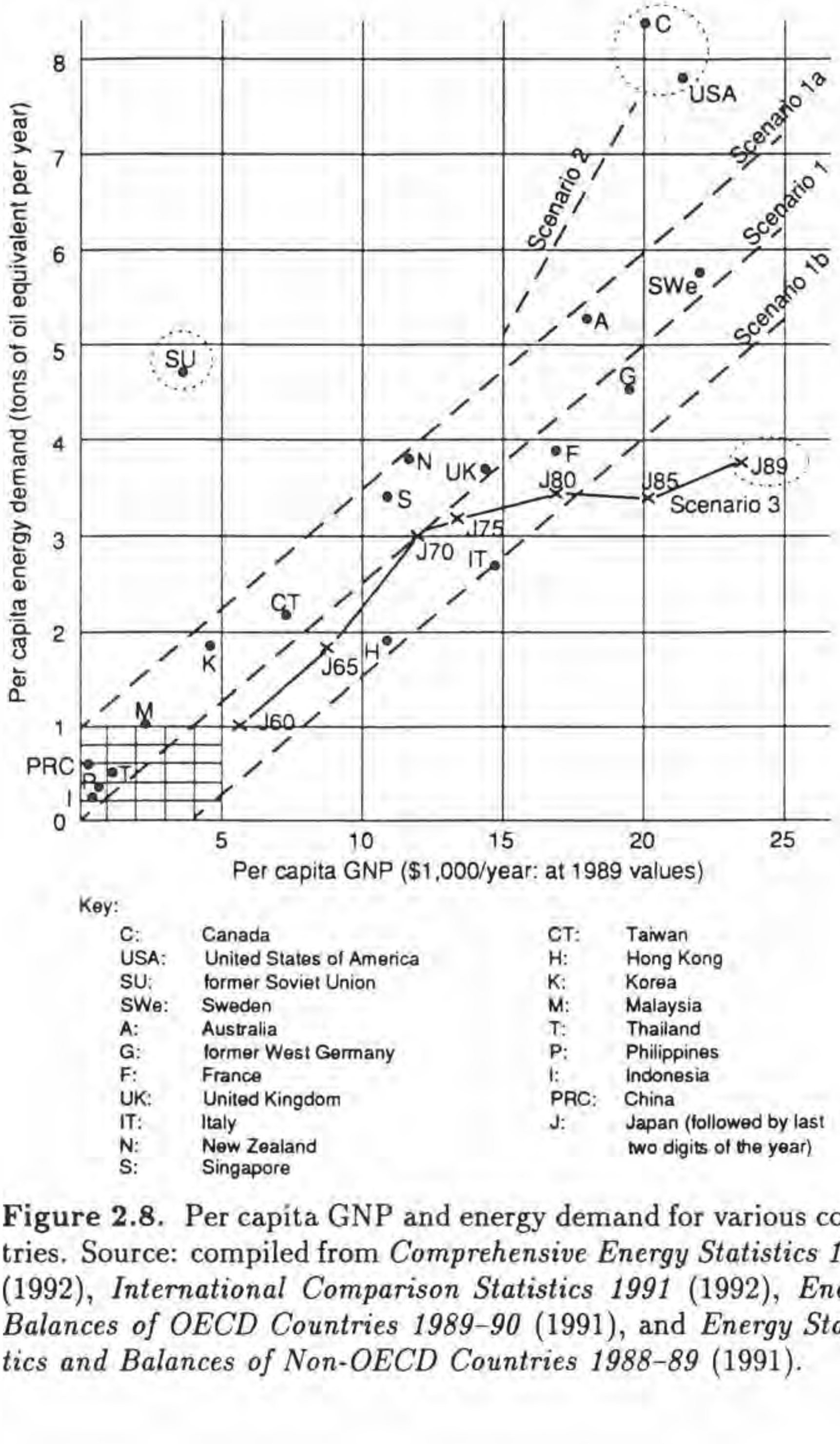


Figure 2.8. Per capita GNP and energy demand for various countries. Source: compiled from *Comprehensive Energy Statistics 1991* (1992), *International Comparison Statistics 1991* (1992), *Energy Balances of OECD Countries 1989-90* (1991), and *Energy Statistics and Balances of Non-OECD Countries 1988-89* (1991).

In terms of per capita GNP, Singapore today corresponds to the Japan of 20 years ago, Taiwan is at Japan's level of 25 years ago, and Korea is nearly equivalent to the Japan of 30 years ago. Hopefully these countries will benefit from the experiences Japan went through as it strived for energy conservation. It is also hoped that the other developing countries expected to join the NIEs soon, like Malaysia, Thailand, Indonesia, and the Philippines, will follow not scenario 1a but 1b, and eventually scenario 3, because this would help the growth of developing countries and advance the international competitiveness of their industries, contributing simultaneously to conservation of the global environment.

Proposals

- *Set up a system for international cooperation to make energy conservation technologies successfully applied by developed countries available for sharing by developing countries as international assets of the public domain.*
- *Facilitate the transfer of energy conservation and environmental technologies to those former Soviet republics whose per capita GNPs are substantially low by objective standards by applying Official Development Assistance (ODA).*
- *Encourage those countries with high energy requirements with respect to GNP to reduce their consumption by applying the pledge-and-review formula.*

Decarbonization of Energy Sources

Three regions holding the key to the successful reduction of CO_2 emissions

Figure 2.9 shows CO_2 emissions from fossil fuels as related to population sizes (x axis) and per capita CO_2 emissions (y axis) by region (based on actual figures for 1989). It is obvious from the figure that the USA, the former Soviet Union, and China are the three largest contributors of CO_2 emissions, together they account for 52% of the total CO_2 emissions worldwide. They are commonly characterized

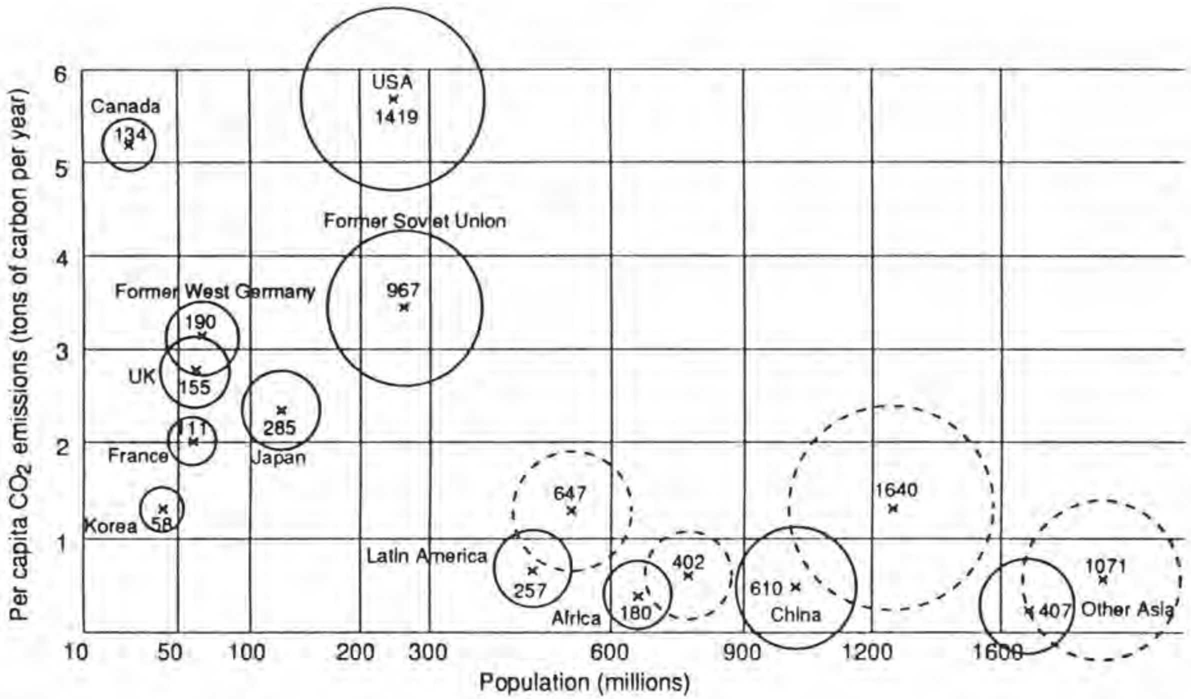


Figure 2.9. CO_2 emissions from fossil fuels by region in units of million tons of carbon (tc). Dashed circles indicate CO_2 emissions assuming a 10% population increase over the 21st century and that per capita CO_2 emissions for each country reach the level of the region immediately ahead. Source: compiled from *World Population Prospects 1985-90* (1991), *Energy Statistics and Balances of Non-OECD Countries 1988-89* (1991), etc. Partly estimated by the author.

as countries where large volumes of coal are produced, energy costs are low, and there is a lot of room left for improvement and further investment in energy conservation/environmental technologies and environmental protection.

The developing countries are least conspicuous with respect to CO_2 emissions, with the exception of China. Their per capita GNP and per capita energy consumption are very small, while their populations are large, resulting in small per capita CO_2 emissions. However, they have tremendous potential for growth as their populations are still growing rapidly. The figure also shows an attempt to ascertain the extent of the impact these countries could possibly have under certain assumptions.

The assumptions are: CO_2 emissions are frozen at present levels for all areas other than the four developing regions of Africa, Latin America, China, and "Other Asia" (Asia minus China, Japan, and Korea); the populations of these four regions grow 10%; and their per capita CO_2 emissions reach the level of a country immediately ahead of them on the chart, considering the parameters of population and per capita CO_2 emissions. These assumptions might be realized within a decade.

Then, due to the large sizes of their populations, the CO_2 emissions of these four regions will jump, with China and "Other Asia" passing the USA and the former Soviet Union respectively. The resulting increase in the CO_2 emissions of these regions combined will raise the total CO_2 emissions in the world by 40%. If per capita CO_2 emissions in each of these four regions reach the present level of the CO_2 emissions of Korea, it will be enough to increase the worldwide total of CO_2 emissions by as much as 80%.

What this means is not that the growth of developing countries is a threat to be contained, because, obviously, each country has its own right to development, but that any discussion on environmental issues would be meaningless without considering these factors in developing countries.

To cope with CO_2 emissions, it is currently proposed to freeze and stabilize emissions at the present levels of industrial countries by 2000, and after 2000 to reduce them. However, this formula raises three basic questions. First, per capita CO_2 emissions vary significantly between countries, being high above the world average in some and well below in others, and it is unfair to give them all the same starting point. The second question raised concerns inadequate consideration given to developing countries.

The third question is the cost efficiency of investment to improve CO_2 emissions. The cost performance of such investment varies greatly depending on whether it is made in a country with high per capita CO_2 emissions or in a country with a low emission level. If all regions in the world are considered equally open for investment, then investments flow selectively into the countries with high per capita CO_2 emissions. Thus, quite obviously, by letting them follow the principle of equalization of marginal production, their efficiency will be maximized to reduce CO_2 emissions in total. Efforts to control global CO_2 emissions should therefore focus on the USA, the former Soviet Union, and developing countries.

Proposals

- *Instead of industrial countries agreeing to stabilize their CO_2 emissions at the 1990 levels, a system for international cooperation should be sought to promote cooperative programs to help countries with per capita CO_2 emissions high above the world's average to improve.*
- *Countries with per capita CO_2 emissions well below the world's average should try to contain emissions at their present levels.*
- *Promote the international transfer to developing countries of technologies for energy conservation, combustion control, and environmental protection.*

De-fossilization of fuels for electric power generation

There is a marked shift toward electric power as an end-use energy form. It is a trend common to all countries, developed and developing, and is probably due to those attributes of electricity that make it a safe, hygienic, energy saving, easy-to-control, and effective (in data processing) source of power. What it means, then, is that while encouraging this shift to electricity, converting electric power generation fuels from fossil to other, non-fossil fuel should immediately help to improve the environment.

Figure 2.10 shows electricity generated by non-fossil fuels relative to CO_2 emissions for the electricity generated in seven industrialized countries. *Table 2.2* shows the split between hydro- and nuclear power. The figure raises three points. First, as a matter of course, there exists a reverse correlation between them (i.e., the more power generated by non-fossil fuels, the less CO_2 emissions there are). Among the seven countries, France and Canada show an outstanding performance. This is due to the fact that in France nuclear power accounts for 75% of the total power generation and hydro-power resources also abound: these combine to push up the percentage of power generation from non-fossil fuel to 87%. In Canada the figure for non-fossil fuel electricity is 74%, which is attributable to a high percentage of hydro-power generation, i.e., 58%, reflecting Canada's plentiful hydro resources coupled with utilization of their CANDU reactors for nuclear power generation.

Secondly, similar percentages of electricity from non-fossil fuels do not necessarily mean similar levels of CO_2 emissions. This is because the latter depends largely on the types of fossil fuels in use, which varies from country to country. In the UK, the USA, and former West Germany, for example (all coal-producing countries) more than 50% of the total fuel used for power generation and over 75% of fossil fuels are accounted for by coal, a source of higher CO_2 emissions. Hence their positions above the trend line L. On the other hand, Italy and Japan, where coal forms less than 20% of the fossil fuels in use, are below the same trend line.

Thirdly, the figure suggests the directions of policies for each country. In order to shift downward to the right along the trend line L, renewable natural energies should be fully utilized where such resources are available. In countries lacking in natural energy resources, peaceful utilization of nuclear power should be positively pursued.

Moreover, there is a need to shift the trend line down from L to L′. There are two ways to do it. One is to replace coal with natural gas where coal is a predominant source among fossil fuels.

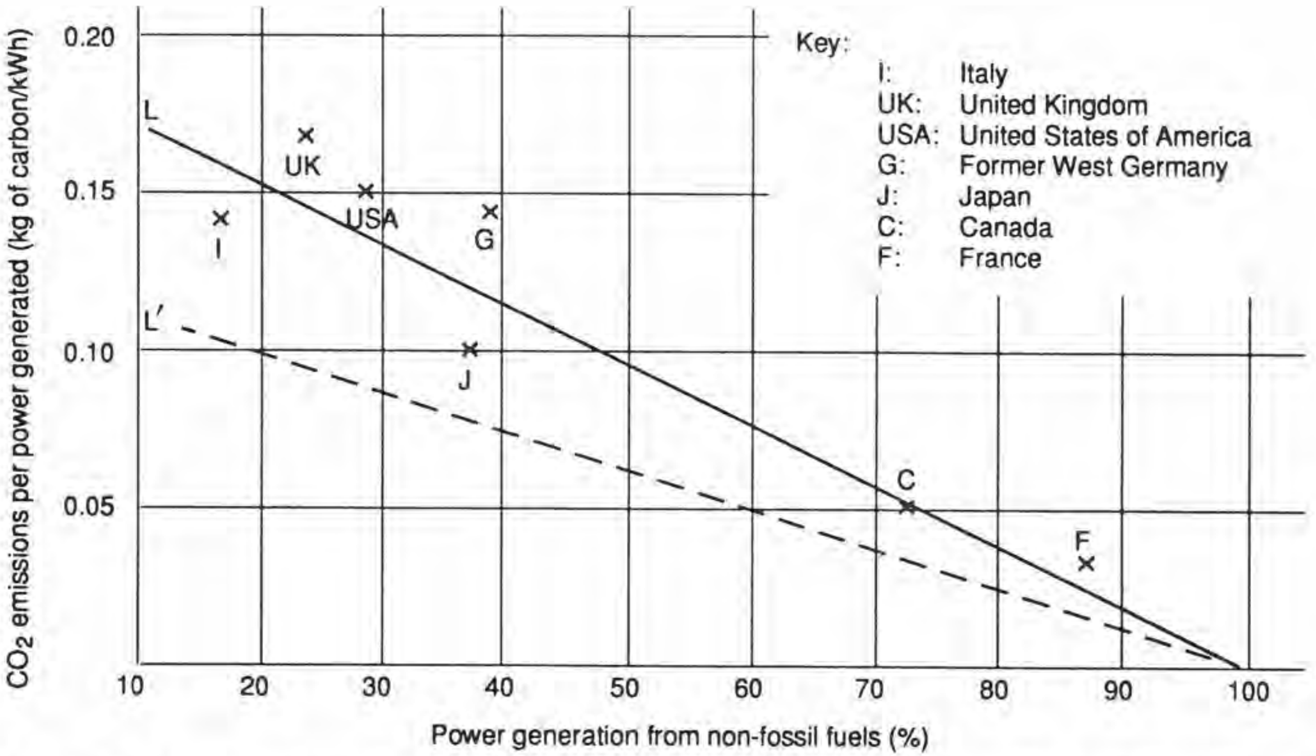


Figure 2.10. Non-fossil fuel power generation (%) and CO_2 emissions (%) in 1989. The non-fossil fuel power for Japan is computed from the data of electric power companies (not including power generation in house). Source: compiled from *Energy Balances of OECD Countries 1989–90* (1991).

Table 2.2. Break-down of power generated by non-fossil fuels.

	Non-fossil fuel power (%)		
Country	Hydro	Nuclear	Total
France	12	75	87
Canada	58	16	74
Former West Germany	4	34	38
Japan	11	26	37
USA	9	19	28
UK	1	23	24
Italy	16	0	16

This should reduce CO_2 and nitrogen oxide (NO_x) emissions from power generation by half and eliminate most sulfur oxides (SO_x).

The second approach is to raise the efficiency of thermal power generation. Remarkable progress has been made in this respect, but there remain two problems. One is that the heat efficiency of steam turbines has peaked, even in the most modern power plant. The second problem is the low heat efficiency of old power plants, which still exist in large numbers in many countries. With respect to the latter problem, what is needed is the modernization of plants by encouraging investment and replacement of equipment. In the following the first point is discussed in some detail.

To break through the barrier of heat efficiency, combined-cycle thermal power generation is necessary. In Japan, as shown in *Figure 2.11* and *Table 2.3*, heat efficiency increased substantially from 19% in 1951 to 38% in 1970, but for many years since then 39% appeared to be the limit. However, the barrier has been broken dramatically by the combined cycle, a combination of gas turbines and steam turbines.

At the Tokyo Electric Power Company's Futtsu Thermal Power Plant, by applying such a system, a total heat efficiency of 43% has been recorded, with the temperature at the gas turbine entrance set at 1,100 °C. A further effort toward improvement is planned for Nos. 7 and 8 units (1.4 million kW each) soon to be built at the company's Yokohama Thermal Power Station by setting the temperature at 1,300 °C at the gas turbine entrance, aiming at a total heat efficiency of 48%. They are fueled by natural gas.

Table 2.3. Past records of heat efficiency at thermal plants (9 electric power generators).

Year	Efficiency (%)
1951	18.9
1960	31.7
1970	37.8
1980	38.1
1988	38.6

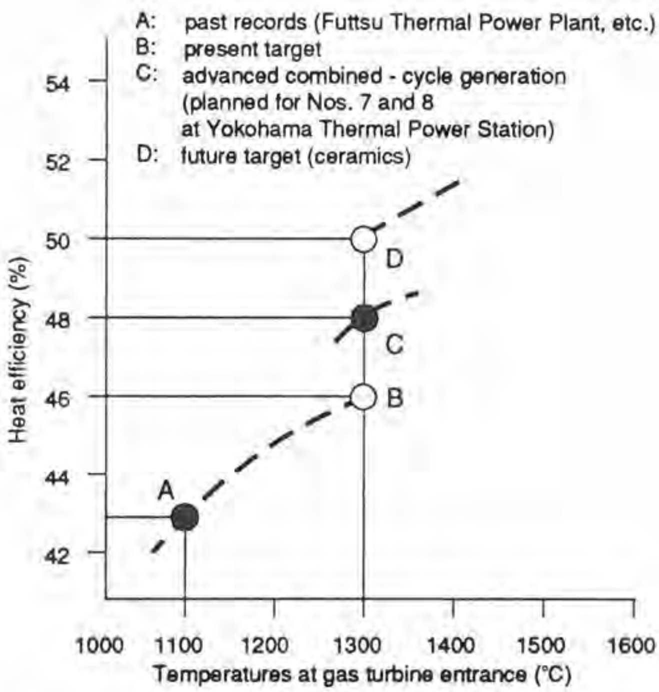


Figure 2.11. Gas turbine entrance temperatures and heat efficiency in a combined-cycle power generator.

An increase from 39% to 48% in heat efficiency does not simply mean 9 percentage points of improvement. There is more to it. A 9 percentage point increase from 39% translates into a 23% saving in fuel consumption, which in turn means a 23% reduction in CO_2

emissions. Indeed, the technology goes a long way to help both energy conservation and environmental protection.

Proposals

- *Positively explore and develop natural energies such as hydro and geothermal wherever possible.*
  - For those developing countries where plentiful water resources remain untapped, a system for international cooperation should be built to help develop such resources.
- *Countries without natural energy resources are urged to pursue safe and peaceful utilization of nuclear power for electric power generation, depending on their levels of technological maturity.*
  - To ensure it is peaceful utilization, international cooperation should be confined to developing countries that are signatories of the Nuclear Non-Proliferation Treaty (NPT) and open to full-scale international inspection by the International Atomic Energy Agency (IAEA). Nuclear power should be provided within the framework of the IAEA and the World Association of Nuclear Power Operators (WANO), thus giving due consideration to safety.
- *With respect to the power generation which still remains fossil fueled, shifting from coal to natural gas in fuel structure should be encouraged and efforts toward improved heat efficiency by using a combined-cycle heat supply should be continued.*

Weaning from oil as an energy source for transportation

Figure 2.12 shows end-use energy forms in OECD countries. After 1973, fuel conversion from oil products to non-oil sources such as electricity has been accelerated in both the industrial and private fields. However, in the transportation sector, there has been no change in the share of oil products, which stands at 99% of all fuel types in this sector (mostly gasoline and diesel fuel oil, some jet fuel and heavy oil). Growing energy consumption in developing countries is mostly of oil for almost exclusively transportation.

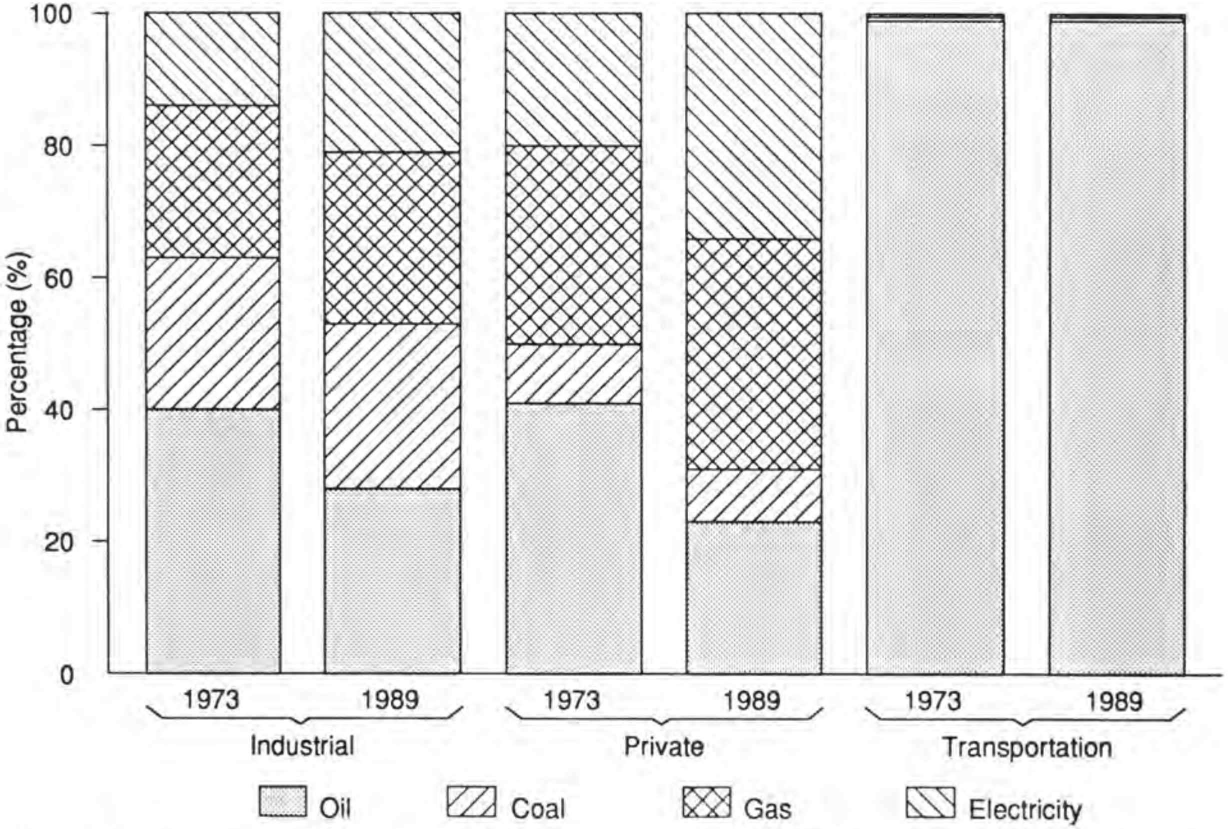


Figure 2.12. Types of energies in end-user demand (OECD). (Figures are in %.) Source: *Energy Balances of OECD Countries 1989–90* (1991).

Oil products have been the best power source for automobiles throughout the past 100 years, leaving no room at all for any other types of fuels to replace them. But the situation is changing dramatically. In view of the finite reserves of oil resources, enormous potential demand in developing countries, and its impact on the global environment, it is time to consider in all seriousness 'weaning from dependency on oil' for transportation.

Specifically, there are two actions required: improve public transportation systems and develop alternative fuels.

Proposals

- *Mass transit systems in developing countries should be given priority for international assistance.*
  - As part of the international assistance for developing countries, priority should be given to the construction of mass-transit systems, with the emphasis on subways (for example, Singapore) and monorails for urban intra-city transportation, and long-distance railways for inter-city transportation.
- *Use a hybrid freight transport system.*
  - For long-distance freight transport systems in industrial countries, a hybrid system is recommended that combines freight cars that run short hauls within city limits and long-haul freight trains.
- *Operate a rapid (railway) transit system as an alternative to airlines and automobiles.*
  - In Japan, with the introduction and the convenient and reliable operation of the Shinkansen rapid railway services, medium-distance freight is being increasingly carried by rail instead of air. This shift in modes of freight carrying is now occurring in long-haul freight.
- *Research, develop, and demonstrate alternative fuels.*
  - Research into and development and demonstration of alternative car fuels to gasoline and diesel oil should be expedited.

- Candidate alternative energies include electricity, compressed natural gas (CNG), and methanol. Solar cars require some more research and development time.
- A new electric car model, IZA, unveiled at a motor show held in Tokyo in October 1991, attracted much attention. However, its present costs need to be reduced. (The specifications were as follows: nickel–cadmium batteries; "wheel-in-motor"; maximum speed 176 km/h; start-up acceleration, 18 seconds from 0 to 400 m; a record distance of 500 km covered by one charge.
- CNG-powered cars also drew attention. In New Zealand, 100,000 CNG cars (5% of all CNG cars) are operating on the road.
- A hybrid system combining different power sources, i.e., electricity for intra-city transport and gasoline and diesel for inter-city transport, merits positive consideration.

Summary

To summarize, the following proposals are put forward.

Proposals

- *Dematerialization of affluence.*
  - Promote eco-fashion, prolong use of durable goods, build attractive infrastructure before indulging the convenience of private cars, and improve school education.
  - Recycle returnable containers, introduce a deposit system, promote the recycling of urban and industrial waste heat, the utilization of renewable natural energies wherever possible, and nuclear fuel recycling by re-processing spent fuel.
- *Separation of energy from GNP.*
  - Reflect full energy costs, including the environmental cost, directly in product prices, which should promote energy conservation.

- Upgrade insulation standards for housing, fuel cost standards for automobiles, and promote district heating and cooling systems which effectively utilize the unused energy of waste heat.
- Set up a system for international cooperation to make energy conservation technologies successfully applied by developed countries available for sharing by developing countries as international assets of the public domain.

- *Decarbonization of energy sources.*
  - Promote cooperative programs to help countries with per capita CO_2 emissions well above the world's average to improve.
  - Set up international transfers to developing countries of technologies for energy conservation, combustion control, and environmental protection.
  - Encourage the development of hydro and geothermal energies wherever possible, and nuclear power where mature levels of technology exist. The advanced combined-cycle system using natural gas would be advisable.
  - Mass-transit systems and fuel conversion in the transportation sector should be promoted.

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CHAPTER 3

Sustainable Energy Development

Umberto Colombo

Future Energy Demand

Predicting our energy future is indeed a difficult task. Major mistakes have been made in the past by using more or less straightforward extrapolation. The procedure for forecasting future energy demand that is generally followed at present is based on demography and per capita consumption. In order to take into account the large variations in per capita energy consumption in various categories of countries, some distinction is made in the analysis according to the level of development and the gross national product (GNP).

Demographic forecasts for the next 10 to 15 years are believed to have a high degree of accuracy: current conditions determine quite strictly the evolution of population for some time to come, so much so that some demographers are prepared to say that up until the year 2000 or 2005 we are talking about history, not predictions. However, small differences that appear from now on in the general trends (including action taken to curb the birth-rate) can result in significantly different scenarios for the long term (UN, 1991).

Even with the most optimistic, low-growth scenario (*Table 3.1*), the world population will exceed 7.5 billion in 2025, twice as high as in 1970. We cannot count on stabilized population levels much below 10 billion people by the end of the next century. Most of the increase will take place in the less developed countries (LDCs).

Table 3.1. UN population scenarios (millions). (Key: W denotes total world; D denotes developing countries; and I denotes industrialized countries.) Source: UN (1991).

		Year				
Scenario		1990	2000	2010	2020	2025
Medium-growth	W	5292	6261	7205	8092	8504
	D	4086	4997	5895	6750	7050
	I	1206	1264	1310	1342	1354
High-growth	W	5327	6420	7563	8802	9444
	D	4117	5134	6204	7372	7978
	I	1210	1286	1359	1430	1466
Low-growth	W	5261	6093	6813	7375	7590
	D	4858	4847	5547	6111	6336
	I	1203	1246	1266	1264	1254
Constant fertility	W	5312	6462	7891	9782	10977
	D	4104	5194	6574	8429	9606
	I	1208	1268	1317	1353	1368

Today, per capita energy consumption is vastly different from country to country (*Figure 3.1*): it can vary by a factor of 10 for "commercial" energy use between the average inhabitant of an industrialized country and that of a developing country. This factor is much larger if we consider extreme cases (for instance it is 90 between Canada and Bangladesh).

Non-commercial energy sources (self-collected fuelwood, agricultural residues and animal dung) constitute an important contribution for LDCs, accounting for more than 50% of the available energy in the poorest countries. Under the pressure of increasing population, fuelwood collection is rapidly depleting forests and timber resources, especially in semi-arid and mountainous regions, contributing to major environmental problems such as deforestation, land degradation, and desertification.

Although, as we shall see, energy consumption is not rigidly correlated to GNP, large amounts of energy are required in the industrialization phase. If developing countries are to emerge from their current poverty, the gap between their energy consumption and that of industrialized countries will have to be reduced substantially.

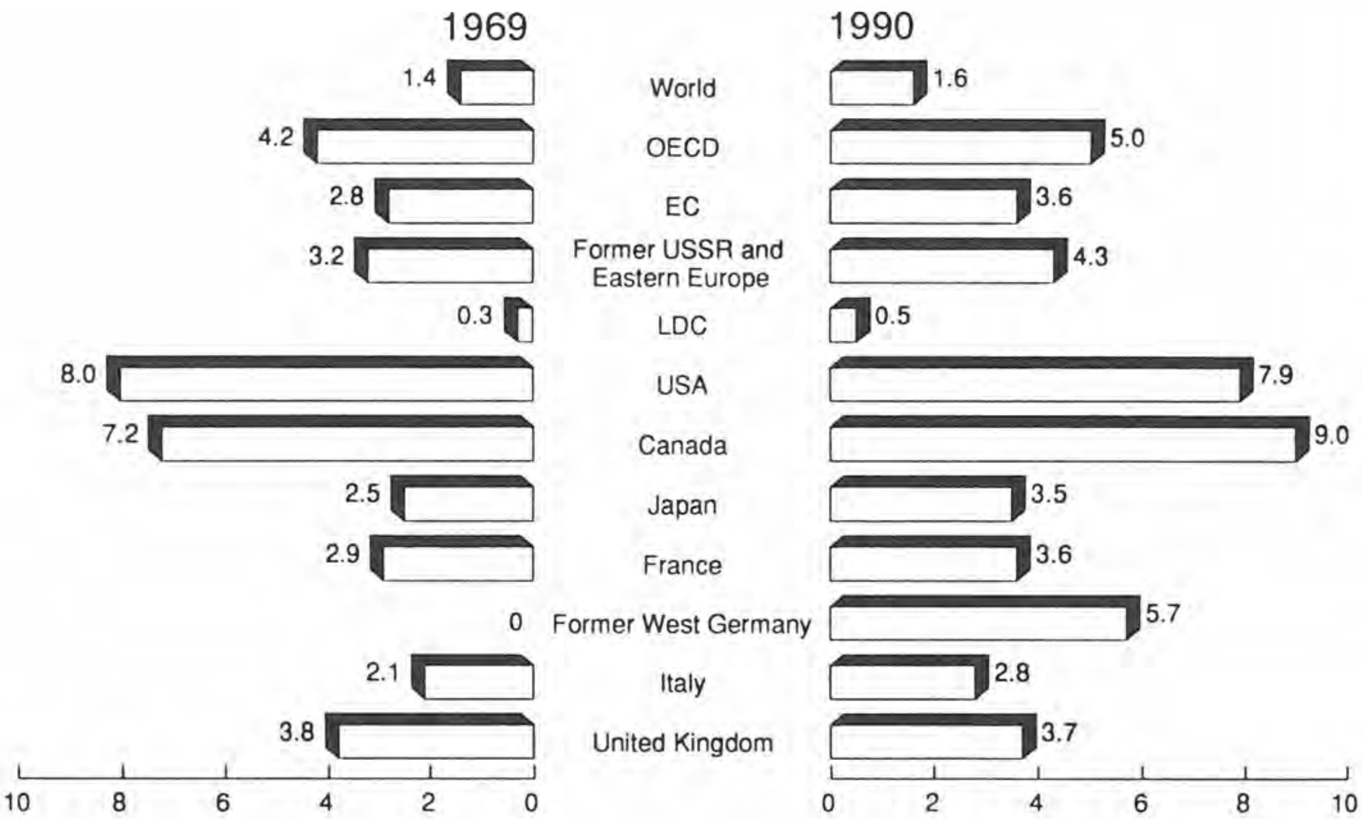

Figure 3.1. Per capita energy consumption (in tons of oil equivalent per person). (ENEA elaboration from different sources.)

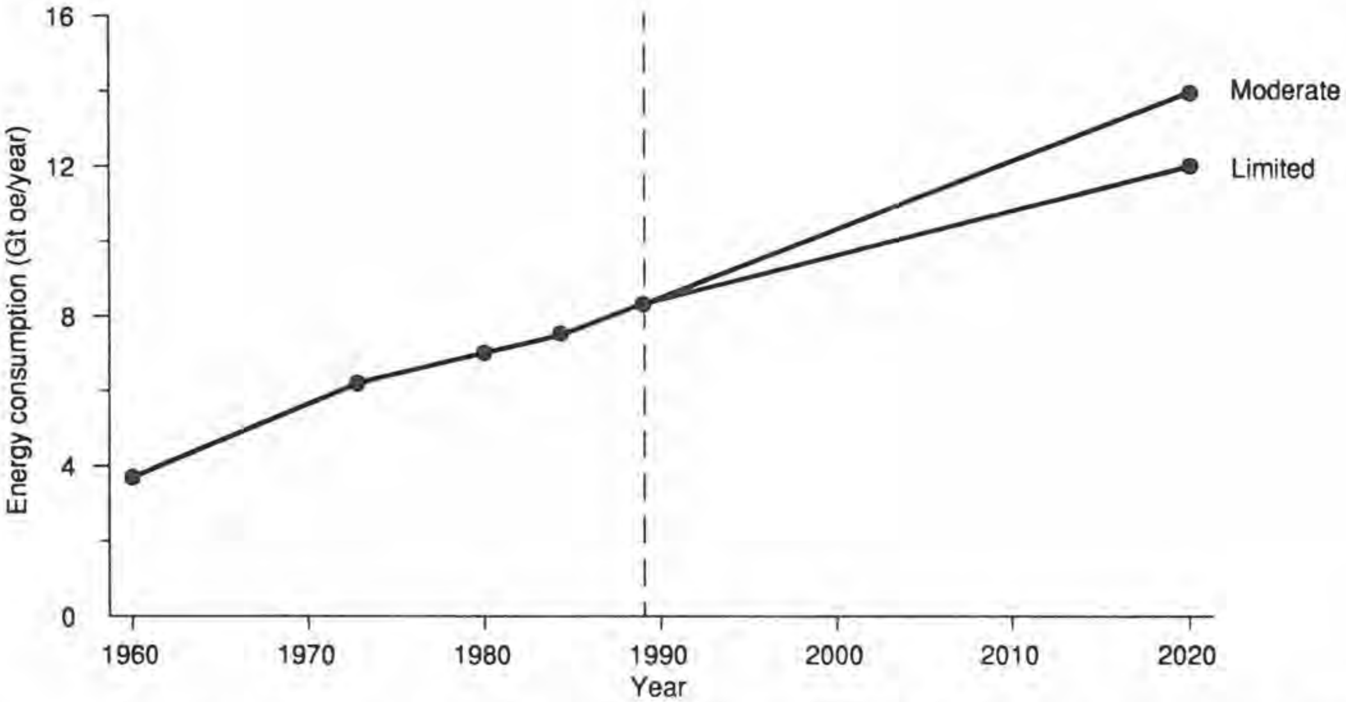

Figure 3.2. Energy consumption projections (including firewood and other biomass outside commercial circuits) up to 2020. Source: *World Energy Conference* (1989).

Starting from these considerations, most current projections of world energy consumption in the next decades indicate quite conspicuous increases, both in the south and in the north of the planet. For example, a group of 30 experts which carried out a study for the 1989 World Energy Conference in Montreal (World Energy Conference, 1989) predicted a rise in global energy consumption of between 50 and 75% for the year 2020 compared with 1988 (*Figure 3.2*). Thus, even in the lowest economic scenario (one which assumes a yearly rate of economic growth of 1.5% in the north and 2.8% in the south), the global energy demand is estimated to reach 12 billion tons of oil equivalent (t oe) by the year 2020. Energy experts seem to have worked quite independently of environmentalists and to have taken little account of constraints imposed by the environment and climate.

Finiteness of Fossil Fuel Resources

The finiteness of resources (for non-renewable energies) is not going to be a major constraint in the short and medium term. Fossil fuels are by far the most prevalent source of commercial energy today. They are derived from a transformation process on a geological time scale, so that they can be considered finite and non-renewable on a human time scale. These resources are therefore being depleted by mankind. This obvious consideration is apparently contradicted by the fact that proven reserves of fossil fuels are not decreasing but, up to now, have actually been rising [British Petroleum (1991): see *Table 3.2*]. Oil reserves have never been so high, having reached (in 1989) an all-time maximum of 44 for the ratio between reserves and yearly consumption. For natural gas, the increase in proven reserves has greatly exceeded the rising trend in consumption, and the reserves-to-consumption ratio is up to about 60 years. As far as coal is concerned, the situation is even less alarming: proven reserves could guarantee more than 230 years of energy supply at present levels of consumption.

The increase in reserves has been faster than their depletion. This is due only in part to the discovery of new deposits. More

Table 3.2. Evolution of oil and natural gas reserves from 1960 to 1990. Sources: *Oil and Gas Journal* (1990), The British Petroleum Company p.l.c. (1991).

Year	Oil (billion tonnes)	Natural gas (billion t oe)
1960	43.0	15.3
1965	50.0	22.4
1970	77.7	33.3
1975	87.4	55.0
1980	90.6	69.8
1986	95.2	86.9
1987	121.2	91.4
1988	123.8	95.2
1989	136.8	96.2
1990	136.5	107.5

importantly, the use of improved, computer-assisted reservoir engineering and geophysical methods has led to substantially higher estimates of the recoverable reserves in the oil and gas fields already known. Furthermore, resources that were considered inaccessible because of the then lack of economically viable technologies or infrastructure to exploit them have now become usable.

If proven reserves have increased, the evaluation of resources has not changed significantly [resources include proven economic and subeconomic reserves, as well as recoverable deposits not yet discovered but believed to exist on the basis of geological evidence: resources represent the ultimate limit of reserves (Gabor and Colombo, 1978)]. It is to be expected that, at least for oil, for which exploration has been carried out in a large part of the globe, the trend of continuing increase in reserves will peak in the not too distant future, and that the ratio of reserves to production will then start to decline. The present estimate, however, only concerns "conventional" resources. If, in addition to the actual discovery of uncertain but expected crude oil deposits, only 15% of the reservoirs of heavy oil and bitumen can be exploited, this would correspond to 120 years plus at present rates of consumption (Watson, 1992). Full utilization of tar sands and oil shales could extend this time limit beyond that expected for coal (Holdren and Pachauri, 1992).

The prospects for gas are more uncertain and potentially bigger, since exploration for natural gas has been limited in the past. Natural gas is also known to exist in the form of hydrates (methane trapped within water molecules under deep oceans and permafrost). No viable technology for the utilization of hydrates is available today, but hydrate reservoirs are estimated to contain 10 times as much gas as conventional natural gas reservoirs (Watson, 1992).

On the whole, the finite character of fossil fuel resources does not involve any real danger of depletion for the foreseeable future, although production costs will presumably increase as less favorable deposits and more sophisticated technologies have to be employed. Anxieties about the security of supply and the price stability of hydrocarbons are more likely to influence energy policies, bearing in mind the ever-present instability potential in the geopolitical areas where the majority of hydrocarbon reserves are located. Political uncertainties and the difficulty of reliably forecasting future energy prices may discourage new investment, especially that which has a long-term pay-back. This might, in turn, generate conditions for future shortages of supply and consequent price rises.

Effects of Energy on the Environment and on Climate

The most stringent limit to the growth of traditional energy use, however, now appears to be the environment. The production and use of energy affects the environment in many ways. The impact of the emissions of certain pollutants (particulates, carbon monoxide, non-methane hydrocarbons, and, to a certain extent, nitrogen oxides) is mostly local and can be dealt with at the national or subnational level. Acid rain is another matter. The formation of sulfuric acid from SO_2 emissions and, probably to a lesser degree, of nitric acid from the emission of NO_x, are the causes of acid rain. This has a regional character, requiring concerted action by more than one country. An even wider impact is the possibility of global climate change triggered by increases in average temperature as a result of the emission of greenhouse gases (GHGs). This could

Table 3.3. Basic facts on greenhouse gases. Source: IPCC (1991).

Gas	Relative contribution to the greenhouse effect over a 100-year period (%)	Lifetime (years)
Carbon dioxide	61.0	50–200
Methane	15.0	10
Nitrous oxide	4.0	150
CFCs	11.0	65–130
HCFC–22	0.5	Short
Others[a] (ozone)	8.5	Short

[a]These values include the indirect effect of these emissions on other greenhouse gases via chemical reactions in the atmosphere. Such estimates are highly model-dependent and should be considered preliminary and subject to change.

have the severest consequences, as climate affects all human activities. Furthermore, it is the most difficult to avoid, involving the biggest uncertainties, and is the impact for which worldwide action is essential.

Such impacts have reinforced the need to apply the concept of "sustainable development" to the energy cycle (World Commission on Environment and Development, 1987) as a way of internalizing external costs relative to the conservation of finite resources, the protection of the environment, and the prevention of disruptive changes of climate. Our energy future also has to be sustainable in economic and social terms, and for the preservation of world peace.

Energy production and use are considered to be the major contributors among human activities to greenhouse warming through the release of GHGs, mainly carbon dioxide. Carbon dioxide is the most important GHG, estimated to contribute about 60% of the man-produced greenhouse effect (*Table 3.3*). The energy cycle, in turn, is responsible for about 75% of CO_2 emissions from human activities, although it contributes only marginally to the emission of other GHGs (mainly methane) (Commission of the European Communities, 1991).

The increase in the atmospheric concentration of CO_2 since the beginning of the industrial age is well documented by measurements taken over a period of several decades and is not disputed. An increase in average temperature, estimated to be between 0.4 and

0.5 °C since 1850, has been worked out from the analysis of historical data [Kelly and Wigley (1990): see *Figure 3.3*]. A majority of scientists now agree that there is enough experimental evidence to support the linkage. Others (Jastrow *et al.*, 1989) point to discrepancies which still need solving: in particular, no increase in mean global temperature was recorded between 1945 and 1970, a period of rising energy consumption. It is true that the measurement of such small temperature variations could be strongly affected by the "background noise" produced by a variety of other phenomena, such as emissions from volcanic eruptions. However, a close correlation between the CO_2 concentration in the atmosphere and the average temperature for the last 160,000 years has been observed from geological data obtained from measurements on ice cores in Antarctica (*Figure 3.4*) (Barnola *et al.*, 1987).

The correlation between average temperature variations and climate change is even more uncertain and difficult to predict. The global climate pattern arises from a complex interplay among many interconnected phenomena, providing both positive (destabilizing) and negative (stabilizing) feedback mechanisms (*Figure 3.5*). They include such phenomena as variations in solar radiation, evaporation, precipitation, the effects of clouds, winds, ocean currents, plant cover, and biological fixation and release of CO_2 on earth and in the oceans, variations in albedo, ice caps, and floating ice, chemical reactions at the bottom of the oceans, and many others. The climate may have a limited stability with respect to changes in the forcing parameters (such as solar radiation and transparency of the atmosphere to different wavelengths), if for no other reason than because large global climate variations have been associated in the past with relatively small variations in these parameters.

Even without dramatic changes in the climatic pattern, relatively small temperature variations may have important effects, for example, on agriculture. Extreme values of temperature brought about by fluctuations may be more important than average temperatures. In the assessment of food security, the impact of climatic fluctuations will have to be studied for different crops and production areas (Sinha *et al.*, 1988). Most climate models predict increased oscillations in the presence of global warming. Effects will

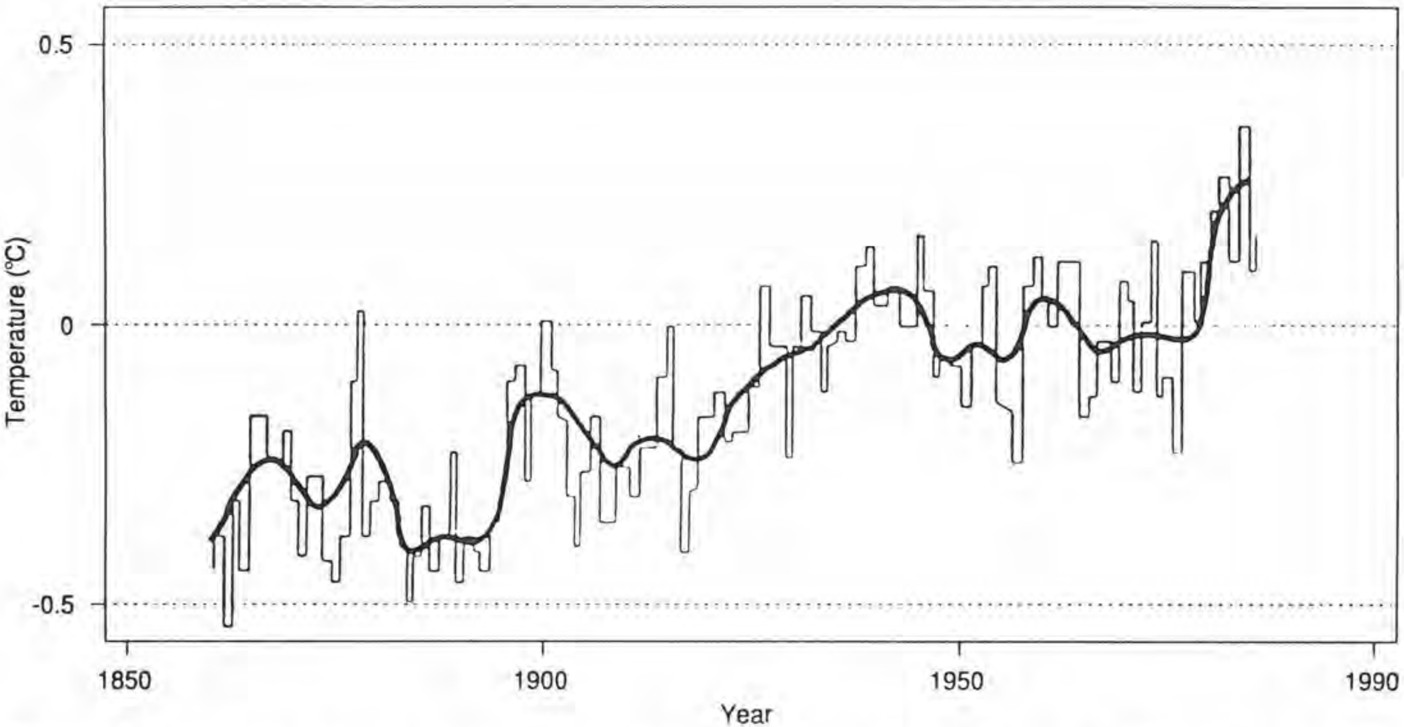

Figure 3.3. Variations in yearly mean temperatures at the earth's surface since 1861. Source: Kelly and Wigley (1990).

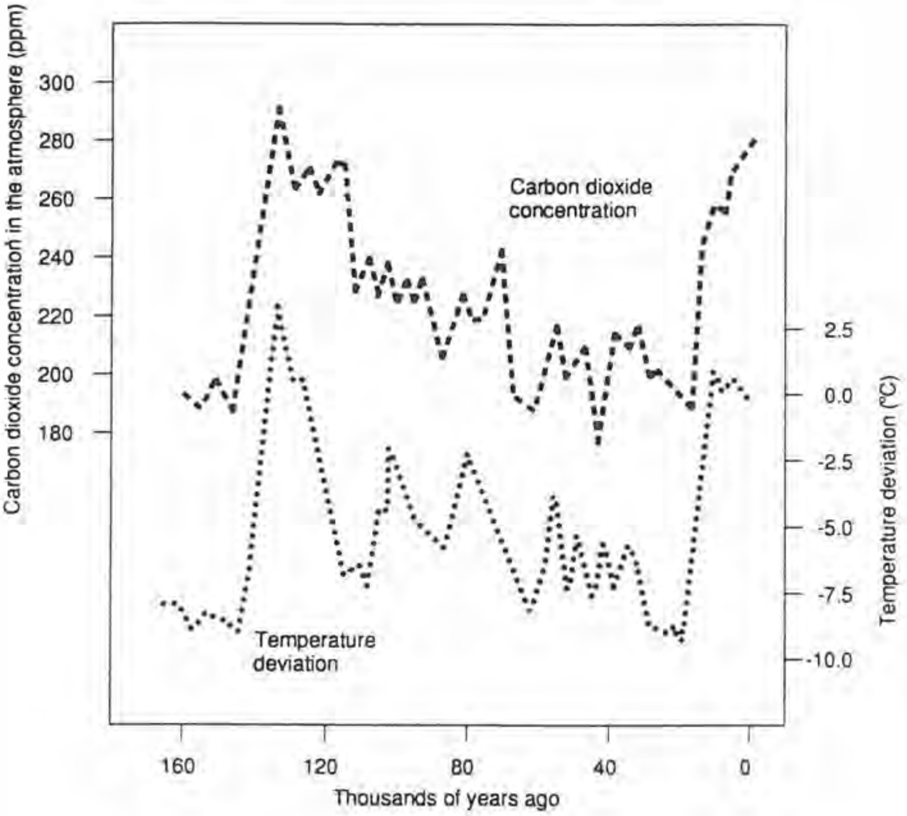

Figure 3.4. Long-term variations in average global temperature and carbon dioxide concentration in the atmosphere. Source: Barnola *et al.* (1987).

vary with geographic distribution and with seasons. Precipitation will be affected: dry regions could become drier, and humid regions more humid. The sea level is expected to rise as a consequence of both the thermal expansion of water and melting of ice in Antarctica, but even this has recently been challenged by the observation (based again on geological evidence) that an increase in snow fall in polar regions may actually override the effects of an increased thaw (Miller and De Vernal, 1992). Computer models, while in agreement on some basic conclusions, often obtain contrasting results

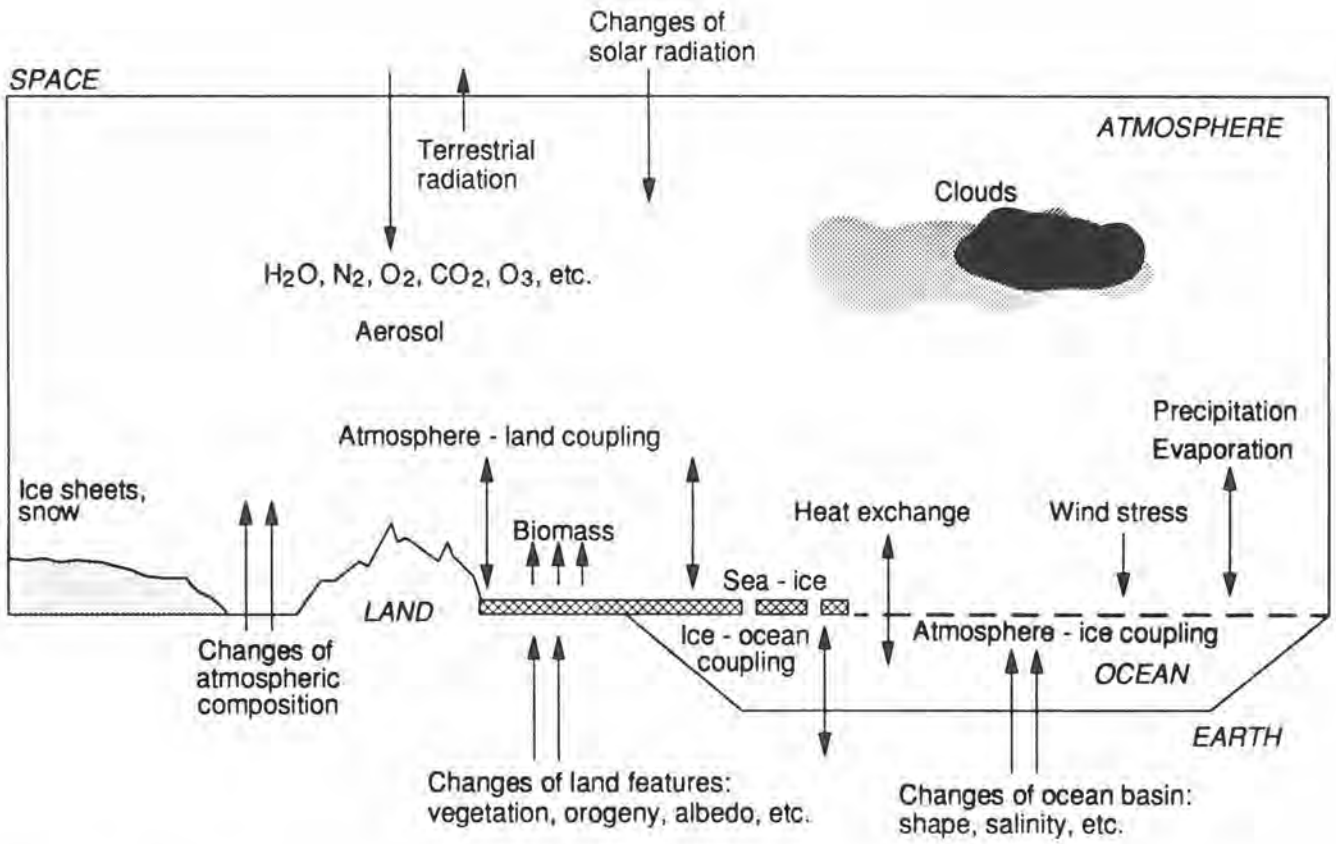

Figure 3.5. Some processes affecting the global climate system.

for the details, especially regarding the geographical distribution of impacts.

Research in the field of global climate change has made great progress in the last several years. Problems have been identified, clarified, and sometimes solved. No definitive solutions, however, seem to have been arrived at, given that each step forward in our understanding of how these processes work discloses new problems and the need to investigate new areas. The problematique is so complex, its various aspects so interlinked, the results of calculations so critically dependent on the details of the representation and on the precise input values, that scientific certainty is unlikely to be reached.

This is presumably not a unique situation (Colombo, forthcoming). Environment and ecosystems are extremely complicated. Now that the global effects of human activities can no longer be ignored, and it is obvious that the self-regenerating capacity of nature is endangered, it will be increasingly necessary to take important decisions in conditions of uncertainty.

In the case of global climate change, there is broad agreement in the scientific community, even if not yet consensus, that theory and evidence point to a non-negligible – in fact to a fairly large – probability that important adverse effects will occur in the future if the present trend of releasing GHGs continues. The combination of this probability with the expected magnitude of the effects is enough to induce concern and to call for preventive action – at least as an insurance policy.

Such preventive action must include all GHGs in a global approach. It may, however, be misleading to place the various GHGs on an equal footing, for two reasons. The first is that they have different residence times in the atmosphere, and therefore the beneficial effects of reducing them appear on a different time scale (see again *Table 3.3*). The second is that there may be interactions between the different GHGs. In particular, this is the case with chlorofluorocarbons (CFCs) (UN, forthcoming). Chlorofluorocarbons contribute to the greenhouse effect. However, international agreement has been reached on their progressive elimination because they deplete the stratospheric ozone layer. The cut back in

CFC emissions, however, may have a less positive impact than first anticipated in terms of containing greenhouse warming, because on their way up to the stratosphere CFCs destroy tropospheric ozone (itself a powerful GHG) by catalytic action.

Limiting CO_2 Emissions

The scenarios developed by the International Panel on Climate Change (IPCC, 1991) consider that the risk of sizable climate change is low as long as the atmospheric concentration of CO_2 remains below 400 ppm (*Figure 3.6*). This is a useful reference point, although somewhat speculative, given the uncertainties of the computational models used in prediction. In order to reach this goal, bearing in mind the inertia of the system, it would be necessary to curb CO_2 emission levels worldwide. If a reduction of 2% per year were implemented, starting from now, the increase in temperature would be confined to a comfortable 0.4 °C. However, if we wait until 2010 for such a reduction, then we start to enter the risk zone.

Action to reduce CO_2 emissions can be costly and produce negative impacts on industrial competitiveness and the world economy. If taken by any given country in isolation, there would be only a marginal effect on climate, at the same time generating severe disadvantages in terms of international competitiveness for the country concerned. There is thus little wonder that many governments are reluctant to introduce such measures. The guiding rule to be adopted in deciding on suitable energy policies must therefore be the "no-regrets" principle. This means taking all those actions which would be beneficial, even if only over the long term, for reasons other than climate change. Should our worries about global climate eventually turn out to be exaggerated, efforts will not have been wasted. In fact, no-regrets policies anticipate what is bound to be the long term response of the market, given that we are dealing with non-renewable resources that sooner or later are going to be exhausted and that, well before then, will become increasingly expensive. No-regrets policies include such considerations as the reduction of indirect environmental costs, social advantages (in

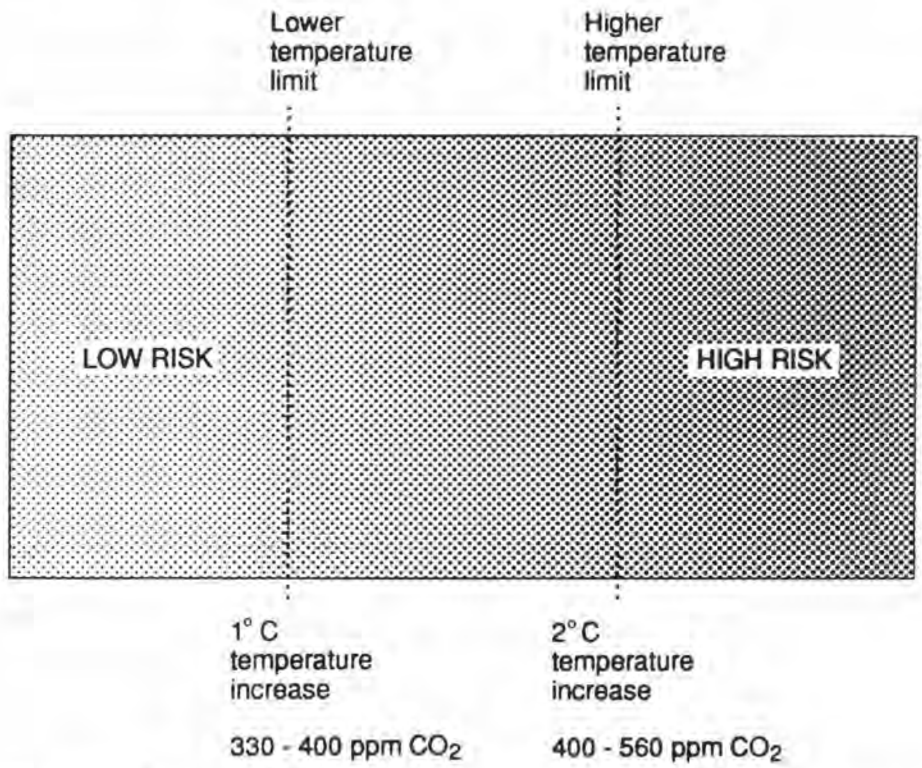

Figure 3.6. Proposed targets for absolute temperature change and equivalent CO_2 concentrations. Temperature targets refer to committed (inevitable) warming expressed in global mean temperatures above pre-industrial levels. Concentration targets refer to stabilized equivalent CO_2 concentrations. Source: Rijsberman and Swart (1990).

particular, cuts in unemployment), balance of payments benefits, higher energy security, etc.

In order to reduce CO_2 emissions in the energy cycle, four courses of action can be contemplated. The first consists of substituting alternative energy sources for fossil fuels; the second in improving the efficiency of energy production and use; the third in fuel-switching within fossil fuels; and the last in sequestering and storing CO_2 after combustion. The last two options offer limited or uncertain opportunities. The substitution, for example, of natural gas for coal is advantageous from the point of view of CO_2 emission by a factor of almost two, provided gas losses are negligible (methane is a much more powerful GHG than CO_2). Such substitution is partly taking place, as a result also of the other environmental advantages of gas, but it is constrained by the higher price of gas with respect to coal and, in a long-term perspective, by the smaller reserves. The last option – separation and storage of CO_2 – could be contemplated for large plants (Marchetti, 1977), but is expected to be very expensive. It has never been tested on a significant scale and has uncertain long-term environmental impacts and safety problems (especially for deep sea storage). The important courses of action are therefore to replace fossil fuels with other forms of energy, and make more efficient use of energy. Both will be examined in the next two sections.

Nuclear and Renewable Energies

Fossil fuels can be replaced by nuclear and renewable energies, neither of which over their cycle of discovery, exploitation, and disposal produce large quantities of CO_2, even considering plant construction. Nuclear fission energy today generates some 17% of world electricity and accounts for over 5% of total primary energy at the world level. Availability of uranium is not a problem. Although proven reserves of uranium that are at present available at a low extraction cost would be sufficient for only a few decades of operation at the current level of installed nuclear capacity, the contribution of uranium forms only a small percentage of the cost of the kWh. Using uranium that costs three times as much to extract as at present would increase the per kWh cost by only 10%. In this case, much bigger uranium resources would be viable, allowing operation at present levels of nuclear capacity for over 1,000 years, or at a much larger capacity for over 100 years, and this without having to switch to breeder reactors (Holdren and Pachauri, 1992). With breeders, no foreseeable limitation on uranium resources would apply, even in a very long time frame.

Nuclear energy is at the moment in a quasi-stalemate situation due to concerns about safety and environmental impact, worries about nuclear proliferation, and poor economics. A new wave of nuclear investment could occur if a new generation of reactors embodying enhanced passive safety features are developed, if waste problems were satisfactorily resolved, and if economic prospects were to improve. Solutions for all these problems are being investigated at present.

Nuclear fusion still has a long (and costly) way to go before it can become a realistic commercial option. Short-cuts and breakthroughs, although possible, are unlikely. Furthermore, it is improbable that either fission or fusion could play a significant role in developing countries for a long time to come, given the high capital intensity and the extreme complexity of the related technologies, not to mention the need for a sophisticated societal organization to cope with the issues of safety and risk.

Renewable energies do have many of the characteristics required to become major components of future energy systems. They do not lead to net carbon dioxide emissions and have few environmental problems, so that they fully qualify as sustainable. They are distributed in nature, and are therefore well adapted for a pattern of development which is not heavily concentrated in urban areas. Renewable energies do not require costly infrastructure, which is generally lacking in, for example, LDCs, when compared with the transportation and distribution systems needed for electricity and natural gas. They are not yet economically competitive with conventional energies, although they offer the best (if not the only) solution for many specific applications, in particular in remote or isolated areas. They may become generally more competitive if various non-technological obstacles are removed (including subsidies given to conventional energy generators, which are especially common in Third World countries) and if external costs are taken into account. Furthermore, a massive effort in research, adaptation, and demonstration supported by public funds (as was the case decades ago for nuclear energy) could produce a breakthrough in use.

Renewable energies are diluted in nature, they require (and imply) a bottom-up approach, with many actors taking small decisions.

This may cause long lead times for their penetration. Furthermore, in the north, where big investment has already been made in centralized infrastructures and where space is in many cases a problem (given the high cost of land), they are generally less competitive than in the south. In an increasing number of cases, however, even in the north, situations are being identified for which renewable energies provide the most cost-effective solution, and at today's low energy prices.

Improving the Efficiency of Energy Use

The last course of action for reducing CO_2 emissions – improvement in the efficiency of energy use – also represents the most important area of action for no-regrets policies. There is no doubt that present efficiency levels, even in the most advanced countries, are far below what is theoretically achievable. This is particularly true when considering the quality of energy (i.e., exergy). The use of electricity or of a gas flame at 1,000 °C to heat water for a bath, even if sometimes practical, is a very poor application of the Second Law of Thermodynamics. An important part of the potential for increasing the efficiency of energy use is not only achievable with existing technologies, but also makes economic sense today, especially if the indirect costs of energy are taken into account. Institutional and attitudinal obstacles have to be removed, opportunities diffused, and technologies adapted to particular applications.

Reducing the amount of energy needed to obtain the same product or service is not the only way to conserve energy. In advanced societies there is a spontaneous trend toward dematerialization (Colombo, 1989). This process involves a trade-off between material goods and information, the substitution of services for goods, a reduction in size and weight of goods (that is, miniaturization), and the substitution of traditional materials by new functional materials. Dematerialization applies to energy as well as to the materials themselves (see Chapter 2 by Tokio Kanoh which deals with this issue in more detail).

An insight into these aspects can be obtained by considering the energy intensity of the GDPs of various countries and their evolution over time. In a primitive stage of development, energy (including both commercial and non-commercial sources) is used very inefficiently, and the energy intensity is high. Studies carried out at IIASA (Nakićenović and John, 1992) indicate that, at least in these early stages, the total energy intensity of GDP decreases as development proceeds; in particular, commercial energies tend to be used with a much higher efficiency than non-commercial ones. In the following discussion, however, we shall consider energy intensity only as the ratio of commercial energy to GDP. This is because the evaluation of the contribution of non-commercial energies is affected by large uncertainties and also because this parameter seems more meaningful and does not overemphasize the effect of the very low efficiency in the use of self-collected fuelwood or residues.

In *Figure 3.7* the energy intensity of GDP is given for several OECD countries over the last 20 years. All these curves show a decrease in the energy intensity of GDP with time. It should be noted that in any given country undergoing economic development up to and beyond the stage of full industrialization, the energy intensity of GDP evolves over time (and, hence, with the growth of GDP itself) and follows the path of the various curves in *Figure 3.8* (Colombo, forthcoming). In an early stage of economic development, the energy intensity of GDP rises because a country needs to build its basic infrastructure, which demands a large quantity of material goods, and also because of the shift in agricultural practices toward energy-intensive inputs and technologies. Continuing along the path of economic development, once the need for basic goods and infrastructure is saturated, demand is diverted toward goods with a lower materials (and energy) content per unit value and toward services.

As might be expected, a country undergoing industrialization later than others will have better technologies at its disposal – reflecting progress in the efficiency of use of materials and energy – and thus will exhibit a lower peak on the curve. This is confirmed by observing, in *Figure 3.8*, the curves representing the real situation in selected OECD countries, starting as far back as the early 19th century. We see that the United Kingdom, the first country to have industrialized, exhibits the highest value at its peak

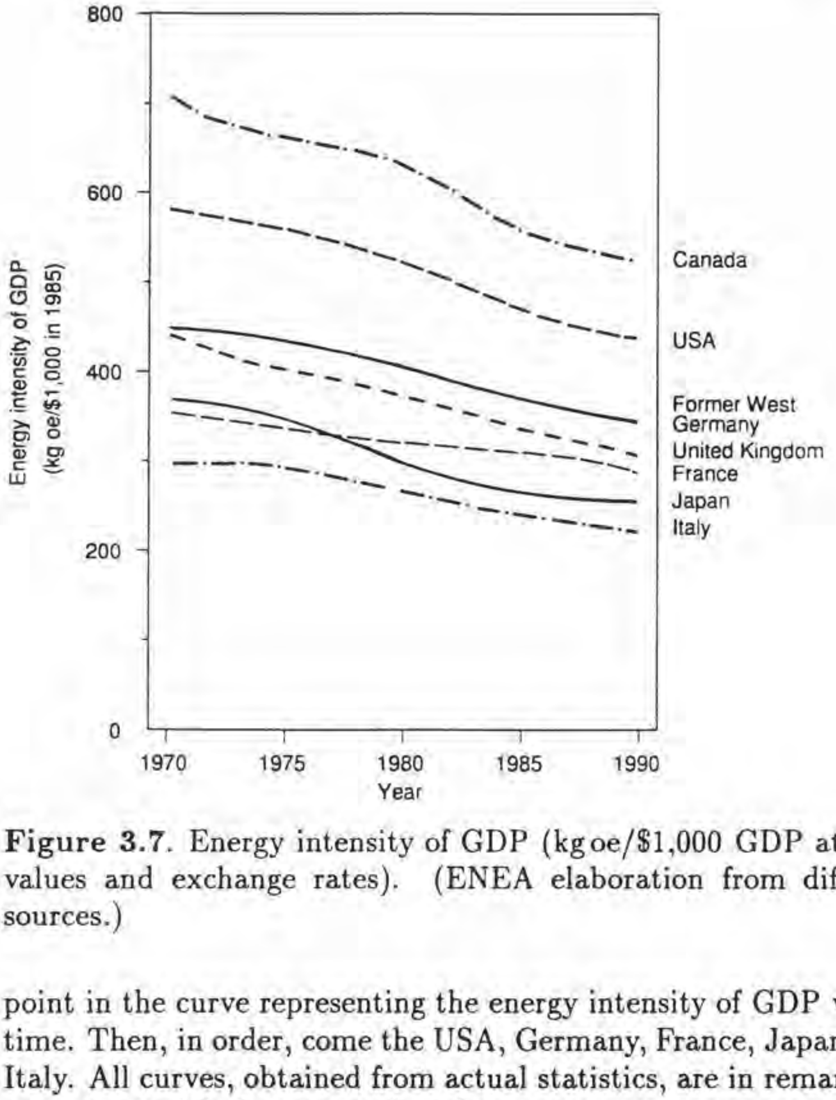

Figure 3.7. Energy intensity of GDP (kg oe/$1,000 GDP at 1985 values and exchange rates). (ENEA elaboration from different sources.)

point in the curve representing the energy intensity of GDP versus time. Then, in order, come the USA, Germany, France, Japan, and Italy. All curves, obtained from actual statistics, are in remarkable agreement with the expected performance.

Now, as one would expect, for the aggregate of Third World countries (the LDCs) the curve in *Figure 3.8* is still rising steeply, indicating that they are still (on average) far away from industrialization. What is worrying in this curve is that the energy intensity of GDP has already reached values higher than the peaks in the curves of Japan and Italy, that is, of those countries in the north that reached full industrialization most recently. This situation

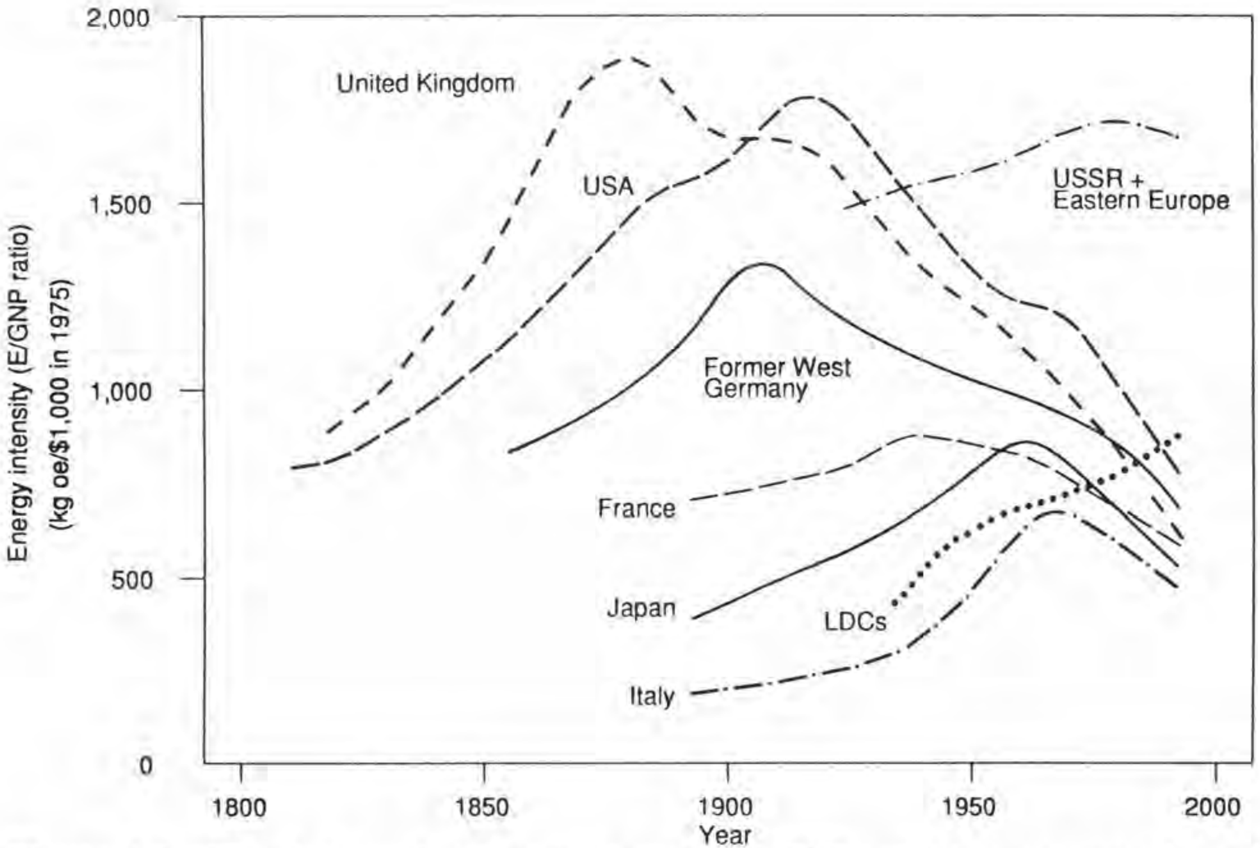

Figure 3.8. Historical trends in energy intensity (E/GNP ratio) in some countries and groups of countries (kg oe/$1,000 in 1975).

indicates that modern, high-energy-efficiency technologies are not generally available in developing countries. This, in turn, is due to the lack of capital for the acquisition of these technologies, to an insufficient technical background, to inadequate education and training, to different priorities set by governments, and, last but not least, to the fact that aid programs run by the North have given higher priority to the transfer of conventional plants and technologies than to the development of energy technologies appropriate to the conditions and needs of the developing countries.

An even worse situation is that of the former centrally planned economies of Central and Eastern Europe and, in particular, the former Soviet Union. For these countries (*Figure 3.8*), the energy intensity of GDP curve peaked only in the 1980s. However, the peak value corresponds to a situation that would have been normal in the West with the technologies available in the 1920s or 1930s. In other words, there is no sign in this curve of the use of the modern, energy-efficient technologies then available which would have allowed a lower peak. The Soviet Union and, to a large extent, the other Comecon countries were not open economies exposed to market forces and competition, a situation which clearly did not favor innovation. The artificial, top-down nature of the pricing structure and the fact that the energy sector was highly subsidized, also explain the exceptionally high values for the energy content of the GDP. For further details see Chapter 4 by Georgi Golitsyn.

Finally, the attainment of ambitious goals for a reduction in fossil-fuel consumption is difficult in market economies when the international price of these fuels is low. The free market has proved indispensable in optimizing the short-term allocation of resources: but the market is short-sighted and its myopia must be corrected by introducing longer-term signals and accounting for external costs. This is the task of government.

Conclusions

Climate change is a global problem, and as such it requires global solutions. We must invest most in those measures for GHG emission reduction where the return for the investment is highest. Today, this indicates priority for such actions as: improving energy efficiency in the successor states of the Soviet Union and in Central and Eastern Europe; introducing more modern ways of burning coal and other fuels in the still-primitive plants common, for instance, in China and India; reducing methane emissions to the atmosphere in oil fields and leaking gas pipelines. Tradable emission rights may enable the market to direct investment more easily where the returns are greatest. The need is to ensure that all new energy infrastructures are based on technologies that give high efficiency in energy conversion and use.

Although advanced countries in the West are relatively more efficient in their use of energy, this cannot be grounds for complacency. These countries are also much more affluent, and their per capita energy consumption is high. Credibility is inevitably lost when they suggest possible courses of action to LDCs, unless a genuine effort is made in the North to put its own house in order. Action is needed to ensure that decreasing per capita energy consumption can become an element in continuing economic growth.

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PART III

Present Trends Give Cause for the Most Serious Concern

CHAPTER 4

Environmental Aspects of the Transformation of Centrally Planned Economies

Georgi S. Golitsyn

Socioeconomic Background

During the last two or three years the European countries that formerly belonged to the so-called centrally planned economies (CPEs) started to undergo a rapid transition to, as they declare, a market economy. The state and fate of the environment is a very direct consequence of the state, history, and fate of the economy, public awareness, education, and determination. Thus, we should briefly look at these conditions before we start to discuss ecological problems and possible ways to solve them.

We will consider Poland, Czechoslovakia, Hungary, Romania, Bulgaria, and the former Union of Soviet Socialist Republics, which has now separated into various different countries. On 21 December 1991 many of these countries formed what is now called the Commonwealth of Independent States (CIS). The biggest of these states, the Russian Federation, is not itself immune to further disintegration because of the many nationalities populating it, the fast deterioration of the economy, and the living conditions of the vast majority of the population. These processes have a lot of positive feedbacks. However, here they are acting in the negative sense by enhancing the processes of deterioration in the former Soviet Union (FSU), and also to some extent in the other former CPEs. We will not consider here the former German Democratic Republic: this problem may be left to the Federal Republic, which has enough resources, determination, and expertize to solve its own environmental and economic problems quickly and efficiently. Also, we will not consider former Yugoslavia in detail because of its woeful disintegration and the current war, nor Albania where reforms are just starting but where no data are available to the author.

The basic problems are common to all the countries but there are some differences which may result in future in their environmental problems evolving and being solved in different ways and on different time scales. Most of the data and information presented here will be for the former Soviet Union, not only because the author is from that country and thus has first-hand knowledge of some of the data, but also because the range and extent of the problems there are larger than in all the other countries together, and the present economic situation is much worse than in any of them, which will make the improvement of the environment more difficult and problematic.

In preparing this chapter the main reference materials used were: the materials of the IIASA Task Force Meeting entitled "The Environment in Eastern Europe: Common Problems and Corrective Actions in the Region", held in Laxenburg, 19–23 November 1990 (IIASA, unpublished); the *National Report of the USSR to UNCED* (Ministry of National Resources and Environmental Protection, 1991); and *Environment of the Czech Republic* (Blue Book, 1990).

Let us consider the common factors among CPEs, the countries under discussion. In the late 1940s these countries began to follow the development path of the Soviet Union, which had started some 20 years before when it became a fully totalitarian state. It was the path of industrialization, in which the state planned industrial development causing grave consequences for the environment. One should remember that until about the late 1960s environmental problems were not a topic of discussion, at least in the part of the world under consideration, but they were also not discussed much in other parts of the world. The peculiarities of industrialization in CPEs are listed below:

- Most investment, up to 85% in the USSR, went to production group A, which involves mining, transportation, energy, and the production of manufacturing systems. Only about 15% of investment went into the production of consumer goods. A similar situation occurred in the other countries with CPEs. As a result, most production was carried out for its own sake, not to supply a consumer need, and at the same time it increased the stress on the environment.
- Centralized planning and governance (I am reluctant to use the term management here because the poor economic performance resulted from mismanagement rather than management!) was based on state property which meant that people lacked real responsibility for the environmental, and very often the economic, consequences of their actions.
- Extreme degrees of industrial monopoly developed when a particular product was produced at just one plant. Obviously the manufacturers were interested only in a quantitative increase in production, not in qualitative improvement. The lack of competition from the world market did not help to improve the situation. This was the main reason for the growing retardation of industries in CPEs in comparison with their Western counterparts.[1] The uniqueness of a plant producing a particular item, or part of it, makes it impossible to close the plant in the event of it causing an ecological hazard, even for a relatively short period of time. For instance, during 1989–1990 many pharmaceutical factories which were damaging the environment were closed down by local authorities, but a drug deficit quickly developed so the central authorities ordered the factories to re-open after supposed quick repairs, or installation, of cleaning facilities. Here, a real dilemma arises if we care about public health: which is more damaging – the absence of drugs or a bad environment, which is also bad for the biosphere as a whole?
- A much larger proportion of GNP was allocated to military purposes in CPEs, especially in the USSR where it was estimated to be about 25%, while in the USA it is currently 5% of GNP, and in Japan only 1%! Therefore, there was always

a preference for military production before civilian production, and as a result there were chronic shortages of capital for the renovation of the infrastructure, and other parts, of industry. This is especially noticeable in Russia and other parts of the CIS, but also in Georgia and the Baltic states, which are not members of the CIS. The average equipment life-time in these countries now is 26 years, while in the developed countries it is only about 10 years.

- There is a lack of concrete information about the state of the environment available to the public in general and concerning particular regions and cities. Only in 1988 was the mark "For in-service use" removed from the yearly "State of Environment" reports issued by the then State Committee for the Hydrometeorology and Control of the Environment of the USSR (now dissolved, reorganized, and hidden within the Ministry of Ecology and Natural Resources of the Russian Federation Government). However, less than a thousand copies of even these unclassified reports were printed. Similar attitudes concerning the concealment of information on the state of the environment by governing authorities could be found in all the CPE countries of Europe [see, for example, Blue Book (1990)].

All these peculiarities had, and still have, very grave consequences for the economies and environments of CPEs, especially for the former USSR. First, their products, as a rule, are of no competitive value today in international markets due to their inferior quality, hence there is a bad shortage of hard currency and growing foreign debts. Large foreign capital investments are needed to make production competitive, but the social, economic, and legal conditions required to attract such capital exist only in a very few places (like Hungary), certainly not in the CIS yet! Countries within the CIS are rich in raw materials but exporting these without exporting value-added products would only increase their industrial retardation and increase the stress on the environment, causing its further degradation.

Second, because of the age of most of the equipment and technologies used, production in CPEs is very inefficient in comparison with modern systems. In the CIS the amount of intermediate products produced per final product is about 2.5 times larger than in developed countries. The main reasons for this are: a much lower amount of useful substance is extracted from mined ores with much greater energy expenditure; a lot more material is wasted at the production stage (e.g., more than 20% of metal is wasted as shavings during its treatment in machine construction); poor production system quality creates a necessity for an enormous amount of spare parts, and the lack of such parts was (and still is in the CIS), together with many other deficits, the main headache (and source of corruption) in countries with CPEs. Old equipment, and its very slow replacement, requires an enormous repair industry which diverts financial and human capital, thus aggravating the situation (this is a case of one of the many aforementioned "positive" feedbacks worsening the situation).

Third, as a consequence of all this the discipline at work is very slack, as well as the workers' awareness and basic care for the environment. This, together with old and unreliable equipment, causes many more accidents than in other developed countries. In many cases, these accidents harm not only people, but also the environment. The most notorious is the case of Chernobyl. The CIS newspapers quite often publish stories about how a particular plant, usually on a Saturday night, opens its containers of liquid waste, which they are supposed to refine and clean, and lets the waste, often toxic, go into the local stream, river, or lake. The local environmental control authorities may charge the plant, but the charge is usually much smaller than the damage, or the price of installing the proper cleaning facilities, or even making the facilities work properly.

Fourth, there is one especially shameful item which is more specific to the former Soviet Union than to the other CPEs. It is the loss of agricultural products during all stages of production from harvesting to the transportation of crops and products, their storage, treatment, and distribution. Nobody knows the exact figures, but they range from between 20 and 30% for meat, eggs, and grain, to between 50 and 70% for vegetables and fruits. Here is just one official example. In the book *People's Economy of USSR in 1988*

(The State Statistical Committee, 1989) one reads that a sampling inspection in state stores found 40% of eggs, 15% of fish, 11% of bread, 10% of cheese, and so on, unsuitable for sale (nobody knows how much was lost before that, or stolen – though theft is just another, uneconomic, form of distribution). This situation is not only one of the main causes of poor living conditions in the CIS, but also a large source of stress on the environment because agriculture in the CIS is more harmful to the environment than in any other developed country.

The state of the food industry and food distribution in the former Soviet Union is the greatest disgrace and failure of the socialist system in its Soviet variant. It is a continuous source of public discontent and humiliation, of large-scale corruption in the storage and distribution systems, and the cause of an increasing national debt due to the necessity of buying an increasing amount of food abroad instead of conserving home produce. As a result, citizens of the CIS view the further deterioration of the environment and the waste of human, financial, and natural resources as only a minor nuisance.

The History and Current State of Environmental Problems in the Region

The nature of environmental problems is the same everywhere, differing only in relative and absolute magnitudes from place to place. The first, and the oldest, environmental problem was the air pollution encountered by prehistoric people when they started to make fires in their caves. Incidentally, they may have experienced enhanced levels of radon (considered now as one of the greatest environmental hazards in the USA today) in some of those caves. Mankind was unaware of air pollution until complaints were made in the 19th century in Great Britain, where soot and acidic emissions started to cause real harm in and around industrial cities. In the regions we are discussing here, air pollution first became noticeable after World War II. In 1949 the USSR Council of Ministers adopted the resolution "On measures against air pollution and on improvement of hygienic conditions in populated places."

The resolution required local authorities to take measures to reduce emissions of harmful substances into city air basins. In the 1950s many republics, now independent states, adopted laws on nature protection. Similar laws were adopted during the 1950s and 1960s by all European countries with CPEs. From the beginning of the 1970s some real action was taken in the prevention of first air, and then water, pollution.

Of course, what has been done during the last 20 years is seriously inadequate and the state of the environment is continuing to deteriorate for reasons we have described in the previous section. Nevertheless, one must also confess that without the measures taken during those 20 years the situation would be considerably worse than it is now. The professionals from the former USSR Ministry of Natural Resources and Environment Protection told the author that before about 1985–1986 the deterioration of the environment in that country was considerably slower because real action was taken to protect the environment. It is difficult to present precise numbers here, or to give exact causes for this, but one thing is certain: there has been a deterioration in technological discipline in industry since the start of perestroika. People working in industry explain this by saying that it results from the introduction of the election of the directors at manufacturing plants, and from the process of democratization without an increase in public social responsibility. Many people in the CIS consider the decline of social responsibility to be one of the dangers of the transition period. In the history of Russia there is a very perilous precedent of the result of a decline in social responsibility: this is the February 1917 revolution when growing anarchy, social apathy, and the disintegration of nationalities in what was the most democratic society of the time cleared the way for the bolshevik coup d'état of October 1917.[2]

Air Pollution

Air pollution is still one of the main environmental problems in the whole of the region in question. It consists of carbon monoxide, CO, sulfur dioxide, SO_2, and nitrogen oxides, NO_x, emissions from burning organic fuels, together with some heavy metals, soot and particulates. Table 2.1 in the *National Report of the USSR to UNCED* by the Ministry of Natural Resources and Environment Protection of the USSR (1991) gives the dynamics of total emissions from 1981 to 1989. It reached a maximum of 108 Mt (megatons = million tons) in 1983 and went down to 95.5 Mt in 1989. The contribution of automobiles to the total emissions is estimated at 39%, although in the 150 largest cities of the former USSR it reached 75–80%, or more. Tables 2.3 and 2.4 from the same source present data on urban air pollution in large cities in the USSR in 1989 and 1990, for dust, SO_2, NO_x, CO, NH_3, H_2S, phenol, formaldehyde, HF, benz(a)pyrene, and some other substances. The number of cities monitored was about 70: for some substances the number monitored reached almost 500.

For most of the substances the average levels reached the limiting allowed concentrations (LACs) adopted in the USSR, or exceeded them by up to as much as three times, as in the case of benz(a)pyrene. Anthropogenic emission was estimated to be about 130 tons/yr in the USSR, while the natural source is about 20 tons/yr. Benz(a)pyrene is produced when fossil fuels are burnt and in metallurgy: in Russia, and elsewhere, it is considered to be one of the most powerful cancerogenic substances, much more dangerous than radioactivity from Chernobyl for many sites (Izrael, 1992). Comparison of data for 1989 and 1990 gives an increase in emissions of 5 to 10% for most of the substances monitored.

Sulfur dioxide is a substance which is required to be reduced by 30% by the Helsinki Protocol. The aforementioned tables reveal no change in its average concentration in 1989 and 1990. The Protocol requires a 30% reduction in SO_2 emissions and its transboundary transfer until 1993. Table 2.2 from the report of the Ministry of Natural Resources and Environment Protection of the USSR (1991) informs us that in the European part of the former USSR the goal had been reached: in 1981 the level of SO_2 emissions was 12.6 Mt/yr and in 1990 it was only 8.7 Mt/yr, i.e., a reduction of 32%. The chief reason for this was the replacement of coal by gas as the main fuel. No data are available yet for 1991, but one may expect some further decrease in emissions simply because of the general decrease in production. For example, on 7 February 1992 Moscow television announced that in January 1992, compared with January 1991, coal excavation had decreased by 12%, and oil production in Russia by 11%. In comparison, one may recall that many EC countries have decreased SO_2 emissions by more than 50% without decreasing their GNP.

Among the worst cities and regions for air pollution in the former Soviet Union are Kemerovo, Bratsk, Norilsk, Apatity, and several others in the Russian Federation, and Yerevan and Alma-Ata, capitals of Armenia and Kazakhstan. The first four have such bad conditions because of heavy pollution from industry (chemical, metallurgical, etc.), the last two have very severe pollution mostly because of cars and bad ventilation due to being situated at foothills or in a valley. Quite often, LACs are exceeded by factors of a dozen, or even a hundred, in those cities during a period of stagnation.

Although the total amount of emitted substances has decreased from its maximum of 108 Mt in 1983 to 96 Mt in 1990, the decrease is mainly in SO_2 and dust, while the amounts of NO_x and many other minor, but harmful, substances are increasing. One of the reasons for this, as noted in the report from the Ministry of Natural Resources and Environment Protection of the USSR (1991), was the system which existed for planning the reduction of air pollution in the industry of the USSR based on the total amount of all substances. Specific substances, such as NO_x and several others, were not highlighted in many cases. To reduce these emissions it is necessary to carry out special studies and design work, reconstruct existing production lines, and apply new technologies, i.e., incur large capital investment, something which is in short supply in the region. Therefore, one may expect further deterioration in the environment due to specific air pollution if production is kept at the current level. If production levels were to shrink further, as we have already observed for two or three years, one may see a decrease in air pollution.[3]

The practical work to control the environment is carried out by city and regional Committees for the Protection of Nature and by Sanitary–Epidemiology Stations in the CIS. They have the power to impose charges on polluters, but often the charge is of symbolical value only and it is, in any case, passed on to the state or consumers.

Quite often during this process corruption flourishes. Meanwhile, state investment in gas-cleaning facilities and in research and development in this field are virtually absent (Barinov, 1992), and the plants and factories causing the pollution have no incentive, determination, or capital to build new purifying facilities. The plants which produce filters and other gas-cleaning equipment make only a few kinds which are out of date, and also have no interest whatsoever in diversifying, specializing, and improving their products. Unfortunately, this lamentable situation may be preserved for the whole of the period of economic reforms in the CIS. Fiscal and legal incentives and requirements, and norms and standards, have not yet been adopted for many substances in many independent states, so a real improvement in the situation can hardly be expected, unless the current deep recession were to end.

The former European CPE countries appear to be in a worse situation at present regarding air pollution than the CIS. The worst problems are in the triangle of southeast Germany, Polish Silesia, and North Bohemia in the Czech republic. In the latter, SO_2 emission exceeds 100 tons/km^2 yr [also in Prague, see the Blue Book (1990)]. To be specific, per unit area, the level of emissions in Czechoslovakia in 1988 was the second highest in Europe after the GDR. This is also true for sulfur deposition. Almost half, about 47%, of the sulfur deposition in Czechoslovakia comes from other countries, mainly from the former GDR (14%) and from Poland (11%). Due to the complicated relief of the country, there are often very bad episodes of air pollution, e.g., the maximum daily average of the SO_2 concentration in Prague in 1990 was registered at 3.2 mg/m^3, which is 80 times the LAC according to the Soviet standards of 1990. Attempts to reduce sulfur emissions in the country are failing, both in the installation of desulfurization units at coal power plants and in the replacement of the coal plants by new nuclear plants. Therefore, the required 30% reduction in SO_2 emissions compared with 1980 levels will not be met in 1993, as it was supposed when the country signed the "Convention on the Long-Distance Transport of Atmospheric Pollution Across National Borders", or in 1995, the postponed date.

With NO_x, prospects are more favorable in Czechoslovakia than with SO_2. There have already been some reductions in noxous emissions by optimizing the combustion regimes of the main polluters: also, a large-scale introduction of catalyzers in the car industry and in existing cars will occur in the near future.

A similar situation can be found in Poland, especially in the southwest. In both countries, as in Germany, such emissions are causing great damage to forests, making soils acidic, and badly damaging historical monuments. In 1986, the amount of sulfur emissions was 4.3 Mt and in 1989 it was 3.9 Mt [which may be compared with 3.7 Mt for the UK, 2.3 Mt for the FRG, and 5.0 Mt for the GDR, all 1986 figures; see Russel (1990)]. One may expect some reduction in sulfur emissions in Poland due to the severe industrial and economic recession. Again, such improvements in the state of the environment do not give much cause for satisfaction.

The situation is better in Hungary. For many years its main energy source was domestic brown coal, and SO_2 emissions at the end of the 1950s reached 12.3 Mt/yr (or half of that for pure sulfur). In the 1960s there were extremely bad cases of pollution in Budapest, with heavy smog and darkness for several hours. Serious measures were undertaken in the 1970s and 1980s to replace coal by oil and gas, to introduce scrubbers in coal power plants, and to construct nuclear power stations. As a result, SO_2 emissions halved in the 1980s, air particulates were reduced significantly, and, consequently, air quality was considerably improved. Further reductions in SO_2 emissions which have occurred since 1989 are due to the industrial recession. The main cause of air pollution in the country is now cars. As a result of all this, NO_x emissions fluctuate and those of CO and volatile organic compounds (VOC) are increasing. However, the beginning of the introduction of catalytic converters, lead filters, and electronic ignition regulation gives hope for an improvement in the NO_x situation also.

The situations in Romania and Bulgaria are similar to the one in Poland, but on a somewhat lesser scale. However, these countries are poorer than Poland, and without substantial investment of foreign capital it would be difficult for them to significantly improve their environmental conditions. These are especially bad in a few particular places due to a combination of heavy industry, unfavorable topography, and meteorological conditions.

Water Pollution

The former Soviet Union is very rich in water resources but they are distributed very inequitably. The southern and southwestern parts of the country, where more than 200 million people live and which have 80% of the industrial and agricultural production, have only 15% of the total river run-off. It is no wonder that the pollution problems are much heavier here than in Siberia. The most serious water problems are in the Middle Asian states and in Kazakhstan: in these states water is also scarce and most pollution is caused by improper agricultural practices (the overuse of fertilizers, pesticides, defoliants, etc.). Almost all the water from the Amu-Darya and Syr-Darya rivers is used in agriculture: the Aral Sea is catastrophically shrinking causing the demise of ecological systems in the sea, around it, and near the rivers. Drinking water shortages and the low quality of the polluted water used for drinking lead to a huge increase in infant mortality, the widespread occurrence of specific diseases and, in general, to what is called the Aral ecological crisis (Glazovsky, 1991; Izvestia, 1991).

Most of the water resources, including underground waters, in the former USSR are polluted, but the level and character of pollution vary greatly from place to place. The main polluters are the industrial and residential sectors, which have inadequate, or totally absent, purifying systems, and the agricultural sector. The percentage of surface waters polluted by the following substances in excess of the LAC is: for oil and oil products, about 45%; organic substances, 35%; detergents, 7%; zinc, 35%; copper, 75%; nitrites, 35%; etc. For some substances the most polluted river in the former USSR is the Danube (Donau). In the *National Report of the USSR to UNCED* (Ministry of Natural Resources and Environment Protection of the USSR, 1991) there is a very detailed survey of the pollution in all regions, their rivers, lakes, and water reservoirs, and of the adjacent seas of the former Soviet Union.

Two great Russian lakes require special attention. First is Lake Baikal, which has the greatest volume of freshwater in the world. Among the main polluters are two pulp and paper mills. Near the estuary of the River Selenga in Baikal a stable area of about 30 km^2 has formed which is polluted by sulfates, chlorides, and organic substances. In this area during the last 10 years 17 out of 27 species of benthos organisms have disappeared, and the biomass of zoobenthos has decreased by a factor of 3.

Much more serious changes can be observed in Lake Ladoga, the largest lake in Europe. Around the lake there are seven paper mills, a large aluminium plant, and intensive agriculture. Only 15 to 20 years ago it was one of the purest lakes and the Neva river supplied Leningrad (now St. Petersburg) with good quality drinking water. The largest increase in a polluting substance was observed for phosphorus, which has increased by a factor of 3 over the last 30 years: the nitrogen level has increased by about 30%. There is a noticeable decrease in pH because of acidic depositions. At the beginning of the 1980s the lake changed its state from oligotrophic to mesotrophic and serious changes in its ecological systems can now be observed. The water supply of the 5 million inhabitants of St. Petersburg is now in jeopardy.

Many other water reservoirs and lakes are in a state of eutrophication or in danger of becoming eutrophic. Another very large environmental problem and source of controversy is the Leningrad dam (I do not want to call it the St. Petersburg dam). The purpose of the dam was to save Leningrad from floods which arise due to wind fetches from the Bay of Finland. Every year there are several floods in which the water-level rise in the Neva river is about 2 m, occasionally the water spills over the banks, but about once in a hundred years there is a major flood affecting large parts of the city. There were intense discussions about the dam in the late 1970s but comments were suppressed and it was decided to build the dam in two parts: from the north coast of the bay to the island of Kotlin where the city of Kronstadt and the Kronstadt naval base are situated, and from the island to the south coast. The northern part of the sand dam was ready at the end of 1984, without any passages, and building started on the southern part. Since 1985, perestroika and glasnost have initiated a very large public debate about the dam. This was fueled by the obvious deterioration of the water quality in the enclosed parts of the bay behind the dam, by the prohibition of swimming or entering the water at the long beaches of the north coast, by the disappearance of fish, and many other signs of ecological deterioration (blooming algae, etc.)

One of the main reasons for the deterioration was the almost complete absence of sewage-purifying facilities in the city. These facilities were supposed to be built before the dam: however, the first part of the construction, treating only about 60% of the city's sewage, was ready only in 1987. Of course, the dam changed the circulation in the separated, shallow part of the bay. The debate is still continuing and there is no clear plan for the next step. It is estimated that the destruction of the dam will be much costlier for the city than its construction, and the city does not have the funds. The inhabitants believe that the city was fine without the dam and that they could live without it altogether, but the First Party Secretary for Leningrad in the 1970s, G.V. Romanov, decided to commemorate himself by erecting the dam. Now the inhabitants are uncertain as to what action to take: meanwhile the ecological conditions are steadily deteriorating. This is one of the striking examples of the voluntaristic decisions of totalitarian society creating new ecological problems which have (almost) no solution.

The water pollution problems which occur in the other countries under consideration are similar to those just described. That is, water pollution by sewage, industrial liquid waste, and water works in small streams, rivers, and wetlands which badly impair their capacities for self-cleaning and enhance water erosion of soil. Pollution from oil products, heavy metals, organic substances, nitrates, and nitrites is common everywhere. Insufficient purification of waste water and sewage is the main cause of bad quality drinking water, impaired water ecosystems, and restricted recreational water activities. The worst water pollution problems occur in Poland; this is not only because of agricultural malpractices and acid rain, but is mostly due to seriously inadequate treatment of industrial and municipal waste water. In most cases, for example, in Warsaw, sewage is simply not treated and is deposited raw into the

Visla river. In 365 other Polish towns, in 1990, there were also no sewage treatment systems (IIASA, 1990; Russel, 1990). All this causes neighboring countries with better environmental practices to demand an improvement in the situation.

The water pollution problem in the USSR attracted considerable attention during the 1970s and 1980s. Purification and the reuse of water in industry became common practices. In 1990, the percentage of industrial water needs covered by this was 72.5%, while in 1976 it was only 56.9%. In 1979 only 63% of sewage and industrial waste water was purified and in 1990 the figure rose to 77%. A low rate of introduction of purifying facilities and enhanced requirements as to the degree of water purification all led, in 1990, to the situation where the required level and amount of water purification had not been reached and only 30% of treated water matched up to new purification standards. Unfortunately, again in the late 1980s, one could also observe an increase in the discharge of polluted waters into natural systems and a considerable decrease in the rate of construction of polluted water treatment facilities [see Figures 1.14 and 1.15 in the *National Report of the USSR to UNCED* (Ministry of Natural Resources and Environment Protection of the USSR, 1991)]. This was probably due to the recession, the lack of funds, and the decline in social responsibility.

Soil Degradation, Deforestation, Desertification, and Biodiversity

The area of land used for various kinds of agricultural activities in the USSR in 1990 was 600.1 Mha, or 6 million km^2 (about 11 times the area of France, or 70 times that of Austria). This was a 7.7 Mha reduction compared with 1985. The area of ploughed land was 225.0 Mha in 1990 and 227.8 Mha in 1985. There was a related increase in the area of forests and bushes from 819.4 to 826.8 Mha, and a decrease in wetlands (mires) from 117.1 to 113.0 Mha, for 1990 and 1985 respectively.

The area of agricultural land (in 1990) was estimated to be about 500 Mha, including 220 Mha of ploughed land. Most of the land, 300 and 150 Mha respectively for total and ploughed land area, has a heavy or light mechanical soil composition and is therefore unfavorable for many crops. Salinized soils, or partly salinized ones, cover 97 and 19 Mha respectively of the total and ploughed land areas, acidified ones with a reduced pH cover 68 and 52 Mha, overwetted ones cover 16 and 3.6 Mha, and areas with an excess of boulders take up 62 and 12 Mha.

Between 1976 and 1990 the quality of ploughed land decreased considerably due to the use of new land of low quality and the use of fertile land for other non-agricultural purposes, and also because of bad agricultural practices. All these processes are still continuing.

Water and wind erosion of the soil are the main causes of its degradation and of the loss of humus. During the last 15 to 20 years the loss of ploughed land is estimated to have reached 8–30% in various regions, and the area of eroded land has increased by about 6 Mha, reaching 475 Mha and 177 Mha for the total agricultural and ploughed land areas respectively. The area of ravines had reached 10 Mha in 1990 and their total length was more than 1 million km.

Water erosion leads to the loss of useful substances from the soil at a rate equal to twice the rate at which they are introduced into it by mineral fertilizers. The eroded material contains about 30% of the fertilizers and pesticides applied to the soil and enters water reservoirs, thus badly polluting them. The damage from this kind of pollution is of the same, or of an even higher, order as that from industrial waste or sewage. The production loss of eroded land is estimated to be between 36 and 47%. The measures which can be taken against water and wind erosion are well known, even at a regional level. However, their mass introduction is delayed by the absence of real owners of the land. In those places where such measures are fully implemented, erosion has been suppressed and production has doubled, or even tripled, with a return on investment taking from one to five years.

The other shortcomings in agricultural practices which lead to serious ecological consequences are also common to all former European CPE countries (see Blue Book, 1990), though they vary in scale and extent. One of these is soil compaction due to agricultural machinery which is too heavy. This leads to a decrease in the ability of the soil to keep moisture, to a decrease in soil ventilation, to an increase in run-off of melted and rain waters, and, hence, to soil erosion and degradation. Crop losses due to compaction are estimated to be between 5 and 25%. The problem is now well understood in the CIS and prototypes of much better machinery have been constructed and tested; but, again, the disintegration of the country has delayed the mass production of such machinery for an uncertain time.

There is rapid deterioration of many arid pastures. The state of the pastures with sandy soils, especially in Kalmykia, the autonomous republic on the northwest coast of the Caspian Sea, is close to an ecological catastrophe. The cause of this is the overuse of the pastures by sheep, insufficient fulfilment of measures for the restoration of grass cover, etc. In the Kalmykia and adjacent Dagestan republics the area of moving sands on pasture land has increased since 1954 from 15,000 ha to 1 Mha, and it is continuing to grow by 40–50,000 ha annually. This is the first anthropogenic desert in Europe!

Similar processes are observed in many places in Kazakhstan and the Middle Asian states. The Academies of Science of Turkmenistan and Uzbekistan have a wealth of experience in fighting desertification and transforming desert lands into productive pastures: they share this with many developing countries which have arid and semi-arid zones. The time needed for a return on the investment of making pastures in arid zones is four to five years. Their productivity will be preserved for 20 to 25 years without additional investments if they are correctly exploited. Again, to apply such measures ubiquitously requires someone to have real responsibility for final production, i.e., making the land private property.

In the tundra desertification has occurred as a result of large-scale mining activities, geological reconnaissance work, and the overuse of reindeer pastures. During the last 20 years about 40 Mha of such pasture was destroyed, an area greater than Germany! There are good plans for the conservation of the tundra, but the question is how and when will they be implemented.

There is also soil degradation in areas of irrigation and drying wetlands. During the period 1970–1990 in the former Soviet Union the area of irrigated land increased from 9.3 to 18.4 Mha. At the same time, 4 Mha of irrigated land was excluded from agricultural use because of salinization and loss of fertility, a shortage of water in the irrigation networks, or degradation. The new area of salinized land is 6 Mha. Huge losses of water from irrigation channels and the enormous overuse of water are the main causes of the ecological catastrophe in the Aral region. The fast decrease in the Aral sea level, about 1 m per year, denudes its bottom, and winds blow salt and dust to distances of more than 500 km away, which increases the salinization of soil.

The area of drained land has increased during the same 20 years from 3.7 to 9.3 Mha. However, about 1 Mha lost its fertility due to overdrainage, especially in Belorussia and the Ukraine where moving sands have formed on the site of some former wetlands, fortunately on a small scale as yet. The useful role of wetlands is now being recognized, and in some regions, for example, Estonia, they are now protected.

During the period 1972–1989 the FSU lost 13.5 Mha of ploughed land due to the growth of bush and low-value forest, use of land for non-agricultural purposes, etc. Most of the losses due to the latter were because of the low financial value of the land as a result of it still being state property.

Intensive acidification of soil is observed in many regions due to acid rain and overuse of acidic mineral fertilizers. Another kind of soil degradation is related to liquid manure from large pig and chicken farms. The manure is removed by hydrosystems and its total liquid volume now exceeds 1 km^3. Only about 30% of it is used for fertilization and the rest is just polluting the environment, especially rivers and streams. Again, there are plans for the reconstruction of existing farms and the construction of new farms without hydrosystems but with other cleaning systems. How and when these would be implemented is very uncertain.

Concerning the forests, there was a slow increase in their total area from 780 Mha in 1970 to 800 Mha in 1980 and 815 Mha in 1990 in the USSR. However, the quality and total biomass of the forest is decreasing, the mature coniferous trees are being replaced by young birch, aspen, and bush. The increase in forest area is related mostly to the abandonment of agricultural lands, but the decrease in quality is due to overcutting good, mature timber forests and increasing forest fires. Massive forest dieback is observed due to air pollution caused by chemicals, as well as the general worsening of the state of forests in many places. The official data are that between 1970 and 1990 about 0.6 Mha of forest died due to air pollution, and more than 1 Mha of forest was damaged. However, satellite data revealed that these figures were reduced by a factor of two or three (Ministry of Natural Resources and Environment Protection of the USSR, 1991). The most striking examples of dieback are: in the vicinity of the Norilsk nickel complex where 300 kha of forest has died; the Bratsk aluminium plant, 140 kha; the area near Irkutsk, 70 kha; and the North Nickel Combinate at the Kola peninsula, 50 kha. Most of the forests, especially in the European part of the CIS, are influenced by a variety of regional pollutions.

The weakening of the forests makes them prone to pests and diseases, which are observed every year over areas of up to 2 Mha. Forests situated around cities are also badly damaged by recreational activities, which lead to the degradation of forest ecosystems in an area of radius 20 to 100 km, thus ceasing the natural restoration of the forests. The degradation also leads to the spread of pollution and disease, and, finally, to forest dieback.

Deforestation leads to a decrease in carbon dioxide extraction from the atmosphere, an increase in the surface albedo, and, therefore, to changes in the radiation budget of ecosystems. It increases the climate continentality and causes a deterioration in the hydrometeorological conditions needed for forest restoration (Ministry of Natural Resources and Environment Protection of the USSR, 1991). In reality it leads to the spread of tundra at the northern boundary of forests (contrary to expectations for undamaged ecosystems), or to the spread of steppes in the south. Deforestation decreases evapotranspiration, which changes the water regime of ecosystems and leads to the spread of mires.

Desert and semi-desert areas cover about 10% of the former USSR (this includes 193 Mha of pasture, more than half this land). At the end of the 1960s the percentage of pasture with open and moving sands was only 5 to 10%: in 1990 it had reached 20 to 30%, which is close to the potential ecological catastrophe of the full loss of pasture. Only about 15 to 20% of pasture is in a satisfactory condition with the flora close to its natural, unaffected state. This leads to an increase in albedo and the worsening of hydrometeorological conditions, which makes the restoration of pasture ecosystems even more difficult and stimulates further desertification. This is another example of a positive feedback acting to enhance a negative effect.

Similar processes are occurring in the other countries under discussion, as can be seen in the Blue Book (1990) and from work at IIASA (1990), but the scale and extent of degradation are less. Unfortunately, these sources do not give figures for different years so it is difficult to judge quantitatively the dynamics of changes in the environment. However, the same problems with soil, humus, soil compaction, overuse of fertilizers, manure which is too liquid, and the pollution of streams are observed everywhere. The causes are the same: people do not consider themselves as real masters of the land and feel no real responsibility for it, as was the case in all totalitarian states.

In the former USSR there are about 2,000 species of trees and thousands of species of grass and many lower plants. There are about 600 wild varieties of cultured plants, which represent the invaluable gene pool. Wild plants give about 12.5 Mt of the most valuable food products. About 2,500 plant species have a potential for medicine, but only about 200 of them have been studied in detail. About 40% of the medicine in pharmacies is produced from natural plants, and half the raw material is collected from the wilderness. The flora is influenced by the same anthropogenic factors as forests and is deteriorating. Many of the plants are now in the Red Book of endangered plants which must be protected at all costs.

For the conservation of flora and fauna the USSR was the first country to introduce state reservations, which are areas without any human activity. Between 1970 and 1990 the number of these reservations increased from 91 to 167 and their area tripled: they currently occupy 21 Mha, i.e., 1% of the total area of the FSU. The numbers of many animals, such as sable, beaver, brown bear, elk, deer, and boar, have increased. However, there is a danger that many states which are now independent will not allocate resources to these reserves or will relax their regime of human non-intervention.

In the author's personal experience, in the area around Moscow and the Central European part of Russia it is true to say that if the biodiversity of flora has not decreased greatly, the number of many organisms has certainly been drastically reduced. There are far fewer birds singing in the forests in spring, hardly any frogs are heard around ponds, rivers, or water reservoirs, and many butterflies have disappeared. Similar data can be found in the Blue Book (1990): in the Czech republic 95% of butterflies have disappeared from the landscape and out of 27 of the most common only 11 exist now. All this is caused by the sequence of pesticides, fertilizers, acid rain, etc. Therefore, the flora and fauna of the CIS and the other Eastern countries require continuing and increasing attention and efforts for their preservation. The extent and materialization of these efforts are very uncertain for the future, especially for the CIS.

The Public Health Connection and Other Socioeconomic Aspects of the State of the Environment

The influence of the state of the environment on public health is clearly seen at the local and, sometimes, the regional level, but not at the national level, especially for such a large country as the former USSR. We will not consider birth and death rate problems here because of the many complications involved in demography. One fact, however, should be noted, that is, a considerable decrease in the birth rate: in 1986 it was 20.0 children per 1,000 people, and in 1990 it was only 16.8. A further decrease is expected in the figures for 1991. Now (in early 1992), in this period of economic reform when liberalized prices are 10 to 100 times higher than in 1990 and salaries have only been increased by a factor of between 3 and 5, young couples are quite horrified at the prospect of having babies. People can feed themselves (and not starve) on bread, cereals, vegetables, and, occasionally, meat: but, in early 1992, there is a shortage of milk and milk products in the larger cities and when they appear for sale people in huge lines pay between 30 and 60 times more than they would have done a year before.[4]

The mean life expectancy in 1989 was 69.5 years (64.6 for men, 74.0 for women): this had remained more or less stable in the preceding 3 years. It is worth noting that between 1987 and 1989 the urban population had a life expectancy which was 1.7 years longer than the rural population's life expectancy, probably due to better medical care. For the years since 1989 one may expect to see a decrease in life expectancy due to worse economic conditions and the lack of drugs.

Life expectancy can be broadly correlated with the regional ecological situation: it is less than average by a few years in the Middle Asian states, Kazakhstan, and Moldova, which are notorious for their poor-quality drinking water as a result of pollution from agriculture. The main cause of death, 56% in 1989, was disease of the blood circulation system: this has decreased in absolute terms from 692 to 641 per 100,000 people since 1980. In absolute and relative terms, deaths from respiration diseases also decreased: from 124 in 1980 to 78 in 1989. At the same time, cancer took 169 lives (per 100,000) in 1980 and 189 lives in 1989. One may suspect that this is due to the increased influence of carcinogens, like benz(a)-pyrene, but a thorough statistical analysis is needed to clarify the relationship. The child (up to 1 year old) mortality rate does show a very good correlation with sanitation and the quality of drinking water. Digestive tract infections are about 10 times more often the cause of mortality in the Middle Asian states than in the Baltic states. The child mortality rate in the region near the Aral, a zone of ecological catastrophe, is 7 times the average over the whole of the former Soviet Union: it reached 150 in 1990 compared with 21.8 per 1,000 newly born babies in the former Soviet Union. The lowest child mortality rate was in Lithuania (10.7), but that country had the highest percentage of children born with anomalies, 43% more than the average over the whole of the former Soviet Union, and 3 times more than in Turkmenistan, which has the highest child mortality rate of 54.7! At the same time, the number of cancers in Turkmenistan is almost 8 times less than in the otherwise well off Estonia, where the cancer incidence in 1986 was about 60% higher than the average over the whole of the former Soviet Union.

In the national report to UNCED five types of territories were classified, with various industrial structures, socioeconomic infrastructure, etc., varying from heavily industrialized territory, such as the Moscow region, to an agrarian one with low infrastructure, such as Middle Asia. They have their own specific disease characteristics. In heavily industrialized urban areas there has been an increase during the last 15 years of children with bronchial asthma by a factor of five or six, while the average factor across the country is three. There has been a general, large increase in allergies which were virtually unknown only two generations ago. We have already noted the 12% increase in lethal cancer cases during the 1980s. The increase is considerably more in highly industrialized regions. There is also a marked growth in lost working time due to sickness and care of the sick.

There are cases of the occurrence of strange, unknown diseases, which are suspected as being caused by pollution by toxic substances or heavy metals. In 1988 a lot of public attention was attracted by the mass falling out of children's hair in the Ukrainian city of Chernovtsy. First thallium was suspected, but then local, national, and international experts had to confess that the reason was not known. Thousands of children, meanwhile, were evacuated from the city. Recently, information that was suppressed gave the cause as being raisins from Turkey which had been treated with pesticides and delivered to the local cake and candy factory: most of the affected children had parents working at the factory.

The same tendencies in the health of the population can be found in other countries (see IIASA, 1990; Blue Book, 1990; Russel, 1990). In strongly polluted areas, life expectancy is several years lower than the average, allergies are considerably more common, and there are more respiratory diseases (for example, in children in North Moravia there is 40% more such disease compared with the average in the Czech republic, and in Prague such disease is between 2 and 4 times more frequent than in smaller, cleaner cities). In the 1980s in Czechoslovakia, the number of pollen allergy sufferers increased six-fold, and ten-fold among children. Noise pollution increases hypertonia, insomnia, and fatigue.

In general, the interrelationship between a particular disease and the state of the environment is complicated and requires significant data base enlargement to analyze the problem. In 1982 in the USSR the Automated State Information System–Health (ASIS–H) was organized: between 1982 and 1990 its data led to the proposal of four groups of polluters. These were: phenol, formaldehyde, SO_2, and H_2S, which cause internal diseases of the respiratory and digestive tracts and the blood circulation system; particulates, NO_x, and CO, which cause respiratory diseases in elderly people, disease of the heart and blood vessels, and skin diseases; benz(a)pyrene, a major carcinogen; and heavy metals, which cause various disorders of the immune and other systems of the human body. At least some parts of the ASIS–H system are left in Russia, but what has been preserved in the other independent states is not known. The whole problem should be an area of well-coordinated, international study, preferably organized by the World Health Organization.

The state of the environment influences not only the physical health of the population, and biodiversity is not only of material value as a gene pool or a pharmaceutical source. A beautiful landscape full of plants, birds singing, and moving fauna is a source of peace of mind and rest in our socially and psychologically disturbed society. Many people value a healthy environment for that reason. The Blue Book (1990) states: "Decaying forests enhance the unconscious aggressiveness, particularly of youths, against Nature, but also against other socially valuable objects". Thus, we find cases of street vandalism and destruction of nature at recreational areas everywhere in the former socialist countries (but not only in them).

The deterioration of the environment also poses a question which has never been seriously considered or worked out in the former socialist countries: that is, the question of intergenerational equity. Do we have a moral, ethical, legal, or any other right to leave behind a much more depressing, poorer, and unhealthier environment than we enjoyed in our younger years? Do we care about our children, grandchildren, and the next generations in general, or do we only care about our own immediate needs? Do we even care about ourselves (remembering numerous examples of considerable environmental change and their increased impacts during the last decade or two)?

We are not considering here global problems such as global warming or ozone depletion. The problems we are considering are the more local or regional ones, for example, acid rain.[5] Most of the developed countries have found methods, technologies, and political determination to cope rather successfully with them, and the state of their environment is considerably better than a generation ago and than it is now in the eastern part of Europe and beyond. Here is just one example (Russel, 1990). In the UK in 1985, in England and Wales 90% of the length of river and canal was of "good" and "fair" quality. The river water in Poland satisfied only about 32% of a somewhat less strict classification and in the Czech republic 44% of river water satisfied the same criteria. In the President's Message on Environmental Quality to the Congress of the United States, George Bush had the full right in April 1991 to write: "... Compared to the conditions facing Americans earlier in my lifetime, our skies are clearer, our lakes and streams are cleaner, and our major technologies are less wasteful" (Environmental Quality, 1991).

The Prospects of Improving the Environment

The immediate prospects of improving the environment may be good in the case of the former socialist countries because all of them are in recession (the CIS has the largest recession), so stress on the environment should be relaxed. Of course, it is very difficult to quantify the improvements, if any (see footnote [3]!). For instance, the 13 February 1992 edition of the Moscow newspaper *Izvestia* announced that in January 1992 12% less oil and 15% less coal were produced in the CIS compared with January 1991 (compare this with the corresponding abovementioned 11 and 12% reduction for Russia), so there are great shortages of fuel in the Baltic states, the Ukraine, and almost everywhere else. These states are now trying to import oil from other countries. Since there is a great shortage of capital, the imports do not cover all the needs. So one may expect less CO, SO_2, and NO_x emissions. However, such reductions are not the result of a positive effort by those states. Moreover, during conditions of disruption in economic relationships, huge recession[6], and a sharp fall in people's standard of living, as in the CIS, maintenance to ensure the proper functioning of environment protection equipment, and its ability to do so, could be greatly reduced, so damage may increase in many places. The recession in the CIS is expected to deepen, at least for 1992, so there might be some prospects for environmental improvement, but with the provisions just described.

New local authorities do not give details about how production units should observe environmental rules, so the units are not interested in the details of the real harm they do to the environment. Therefore, as we mentioned earlier, production falls but pollution goes up.

A slow recession, which started in many branches of the economy of the USSR in about 1985, is not favorable for increasing the attention of industry leaders to environmental issues. A thorough analysis of the USSR's report to UNCED reveals that in the first half of the 1980s much more action was taken than in the second half. To what degree hopes for a better environment in a period of fast recession materialize remains to be seen. A guide as to the reality of such hopes can be found if we look at the situation in Hungary. There has been a decrease in SO_2 emissions there which is ascribed to the recession (IIASA, 1990). The loss of the USSR market for agricultural products has led Hungary into a considerable agricultural recession: again, this has somewhat improved the environment. Similar processes should be observed in other countries.

However, it may be the case that in a few years the recession will stop and economic reforms will succeed. What about the environment then? First of all, one should not forget about it altogether during the bad years of transition and recession. In the Russian Federation at the beginning of 1992 the formation of the "Ecology of Russia" program was announced. What form it will take and what funds, if any, it will be allocated remains to be seen.[7] The other independent states have not even made any definite comments in public on ecological problems. This is not a wise policy. Politicians should remember that political unrest in the Baltic republics started with a strong "green" movement against some ecologically (and economically) unsound projects, such as the phosphate mining and fertilizer plant in Estonia. Soon, this ecological movement was transformed and grew into a movement for, first, economic and then political independence. Most of the new independent states are also multi-national and they should remember this experience.

The worst polluters in many places in the former USSR were closed between 1989 and 1990 by local authorities under pressure from the local green movements. In many cases, these polluters were pharmaceutical factories or unique production plants, so ending their operation stopped the production of a whole chain of plants. In some cases, serious shortages of medicine and massive production losses forced the local authorities, often due to pressure from the central authorities, to reopen these factories and plants, having received an undertaking that they would purify their waste (how that was fulfilled is another question). The straightforward solutions are the installation of new cleaning facilities for sewage and water wastes, desulfurization units in power stations, catalytic converters in cars, etc. Again, this requires capital, i.e., hard currency.

The whole of the economy needs restructuring. The change in emphasis in heavy industry (its conversion from military production to production for civilian consumer needs) should considerably reduce the demand for steel and many other primary materials, the production of which causes heavy pollution. However, this alone will not be enough. An environmental dimension should be incorporated into new development programs using modern technologies and rigorous implementation of environmental legislation (Russel, 1990).

This might be the most difficult part for all the countries. First, all of them are in debt and lack the necessary convertible currency. They should not expect massive foreign aid. They may expect some aid from the IMF and/or the World Bank, but quite often such aid, at least for developing countries, is now given to particular projects which include an obligatory environmental assessment. However, they may expect technical aid in the form of consultants, education, etc. Therefore, they should mostly rely on themselves, their hard work, and devotion to carry out the reforms successfully, to work out good legislation and implement it, to develop real economic incentives for including the consideration of the environment in the economic process. An example of such an incentive could be the release of state subsidies from the energy and agricultural sectors, the main polluters, directly to the natural resources account, resources such as water, land with its minerals, the biosphere, etc. The World Resources Institute (WRI) proposes that this should be considered as the natural capital and should be counted when estimating the functioning of national economies. Such assessments have already been performed by the WRI for Indonesia and Costa Rica (Repetto *et al.*, 1989; Solorzano *et al.*, 1991).

As is noted in Russel (1990), the largest polluters are usually those sectors which are most heavily subsidized, and therefore the most inefficient ones. If the subsidies were to be removed, and if there were proper taxes and incentives in a market economy, those polluters would either quickly reorganize themselves or become extinct. However, as the experience of the CIS shows, it is a long way to a true market economy if one starts from the situation where almost any producer has a monopoly.

To achieve any success, or even acceptance of such measures by the public, a great effort should be made now, especially in the CIS, but also in Poland, Romania, and Bulgaria, to educate people in environmental problems, to make them aware of the problems and to disseminate information, which is only possible through the mass media. This would be especially difficult in the CIS. In the former USSR in the first years of perestroika environmental problems drew the public's attention, and that of the mass media. However, at that time the economic situation was changing slowly. Now, when there is a large mismatch between people's salaries and the prices and availability of goods, and the economy is recessing very quickly, not many people care about the environment. However, this process of education of the public, of administrators, politicians, newly appearing businessmen, and of NGOs must continue. Education of the public is best performed by direct participation in impact assessment and policy development.

The sort of aid which may be valuable and can be given efficiently is a kind of patronage from the countries' closest neighbors, the EC. That organization could determine environmental standards and help to implement them, share its experience in legislation and its implementation, in public education, in advanced environmentally friendly technologies and products, etc.

A lot of new research should be done to establish standards for new substances and, in many cases, to reassess old ones. For this purpose, a sophisticated analysis of medical statistics, together with state of the environment and emission inventories, should be performed. In the CIS there exists a wealth of data on the long-term influences of various levels of radioactivity on human health and the state of the biosphere. The data need systematization and analysis. These kinds of studies are on the agenda for every developed country, and modest grants to do such research would be very helpful in supporting science in the CIS and a good investment for grantors.

However, a genuine improvement in the environment can not happen without a general rise in the state of the economy, and its restructuring, or without the success of economic reforms required to introduce a market economy, with proper economic incentives set by central governments in the form of charges, taxes, or tax relief aimed at helping the environment. Also, only people who are properly fed, dressed, and who have a good standard of living will care about the environment and other spiritual values which have no instant profit. So if the present situation stabilizes at a low standard of living, then people's indifference, the deterioration of the present level of monitoring, and administrative corruption in the implementation of legislation would, eventually, lead to further degradation of the environment, especially in the CIS.

The general strategy for the improvement of the environment – ecologically sustainable development – should be the same everywhere: it involves reducing the stress on the environment as far as possible, using as few as possible non-renewable resources, reducing waste, recycling and reusing materials, and organizing production in such a way that the wastes of one technological line become input material for another. However, to implement these ideas in the form of concrete actions requires a long period of societal education and change.

In most countries the energy sector is a major polluter. There are large areas of potential progress here, both on the production side (cogeneration, the use of a different fuel mix, more renewables) and, particularly, on the consumption and user side, i.e., energy-efficient transport, especially cars and trucks, electrical motors, lighting, residential appliances, house heating, etc. Saving energy must be encouraged. This is not the case at present in the CIS. The author's own institute received in January 1992 the quotas for electricity for the year, with the provision that if we exceed the quota we should pay much more per kWh, but if we remain under the quota, again we should pay more for the unused electricity! This practice must end.

Also, energy efficiency is a major factor not only in curing the economy, but also in reducing carbon dioxide emissions into the atmosphere. Since the greenhouse effect and subsequent global warming is the real global problem, UNCED would probably adopt the framework climate convention. It would need a global solution. The least-cost approach has been used for some time at the state level throughout the USA by many utilities. Among them, the leaders are Pacific Gas and Electric, Southern California Edison, and New England Electric System. These companies expect to meet most of their new demand up to the year 2000 by being efficient and employing energy-saving measures (The Council on Environmental Quality, 1991). Such an accomplishment would be invaluable for Eastern and Central European countries. The least-cost abatement strategy opens up bright, new opportunities for the richer countries. They could invest in emission reduction not in their own economy, which is already quite efficient and to increase the efficiency further and reduce CO_2 emissions would be very costly, but in the developing countries and in the states of the CIS and Eastern Europe, where for the same money much greater reductions could be achieved because of the much greater potential for an increase in efficiency and much cheaper labor, especially in the CIS. If those countries took such a stance, then the prospects for the environment would be considerably brighter. Finland and Sweden are already aiding Poland in reducing its sulfur emissions, which go directly into their countries. Finland and Norway are helping Kola Nickel Combinate to reduce its emissions too.

If we look several decades into the future for the countries in question, and suppose that economic reforms succeed, then the potential for energy efficiency and inexpensive improvements would end. What will be the prospects for sustainable development then? That is the big question. For the developed countries this question may arise much sooner, probably in this decade, before the year 2000. The basic question is: what makes humans on the planet Earth really happy and to what extent should natural resources be spent for people in different places, in the north or south, or east or west. Life will always ask questions which are difficult to answer, but we should find answers anyway, although the questions are becoming tougher and tougher, and finding the right answers becomes more and more difficult.

Notes

[1] The dangers of monopolies were always clear to the Soviet rulers and they avoided them at all costs in the industrial military complex, especially in aviation, rocketry, and satellites where the presence of many firms ensured the competitiveness of the USSR in the arms race with NATO countries.

[2] A contemporary example of social apathy can be seen in the result of additional elections in the Parliament of the Russian Federation in November 1991 in the Yaroslavl region (some 300 km northeast of Moscow). As only 31% of voters came to the polls, it was declared invalid, because 50% of voters have to vote for the election to be valid. In a similar case in Leningrad in June 1991 only 25% of the voters came to the polls.

[3] As the author learned in early May 1992 at the Russian Ministry for the Environment and Natural Resources Use, production in the Russian Federation in 1991 fell by 15%, but pollution rose by 10%. The

reasons for this are many and include the general economic degradation and shortage of funds. In such a situation funds for the maintenance of cleaning facilities are the first to suffer, then problems are caused by aging equipment, the use of old technology, and a lack of general working discipline. Emissions from burning fuels, etc., should go down because there is less to burn, but other effluents can and do, evidently, go up. So all expectations that a decrease in production will result in less stress on the environment should be given up.

[4] The same increase applies to clothes and other goods. The monthly salary of the author, as the Director of the Institute of the Russian Academy of Sciences, after taxes, was enough to buy one tire for a car, 20 kg of medium-quality meat, and one pair of lower-quality winter boots for his wife or daughter, etc. Very soon people will wear out their clothes and shoes and this will be their prime concern. It is not difficult to imagine what people's morale will be like and how much they will care about the environment in the CIS. No increase in production is expected and the situation will not improve until the end of 1992, as President Yeltsin has promised.

[5] From the problems related to climate change at the regional scale, one must mention the dramatic rise of the Caspian Sea level. Since 1977, when it reached the minimum level after almost 50 years of fluctuating decline, it has started to rise continuously due to increased run-off, 80% of which is supplied by the Volga, increased precipitation, decreased evaporation, and the Kara-Bogaz-Gol dam, which was erected in 1980 to prevent a further fall in sea level. The total increase up until 1992 is 1.9 m, which causes major damage to coastal cities, roads, ports, etc., in Russia, Kazakhstan, Turkmenistan, Iran, and Azerbaijan.

[6] In the Russian Federation in 1991 the decrease in production was 14%, and in 1992 it is expected to be 15% (*Izvestia*, 15 February 1992). Similar, or larger, figures can be expected for the other independent states.

[7] No funds have been distributed as of mid-May 1992.

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CHAPTER 5

Pluralism and Convergence in International Science Policy

Sheila Jasanoff

Introduction

The authority of science as an institution has been under siege since the end of World War II. The atomic bomb, the headlong build-up of nuclear arsenals by the superpowers during the cold war, the spate of technological disasters in economically disadvantaged regions of the world, and, most recently, the growing consciousness of the frailty and finiteness of the biosphere – all these have contributed to a public perception of science and its attendant technologies that is as cautious as it is deferential. Technology, from computers to contraceptives, is widely regarded as humankind's primary resource for economic and social betterment, just as scientific research is still prized as one of the noblest applications of human critical thought. As we near the end of the century, however, there is a persistent intellectual unease about the directions of modern scientific inquiry, about the wisdom and integrity of the inquirers, and, most particularly, about the dangers that may follow from an overly intimate alliance between science and the state.

To these manifest concerns, recent academic studies of science and technology have contributed a more subtle strain of skepticism. Is it appropriate for science to claim a cognitive authority superior to that of other social institutions because it alone is able to find out truths about nature? Does the commitment of science to detached and dispassionate inquiry sufficiently justify its asserted institutional right to autonomy and self-regulation? Historical and sociological research over the last two decades has raised doubts on both scores by presenting us with accounts of science that stress its in-built sociality. Scientific knowledge, according to a growing body of work, is a social construct, contingent on human interactions, and susceptible to the multiple influences of economics, ideology, culture, and political interest. Indeed, the closer science draws to the political arena, the narrower the distance seems to grow between the processes of science and politics. In the limiting case, the scientific controversies that so frequently erupt in the course of policy making simply retrace the patterns of more enduring conflicts in society.

Yet scientific and technical experts play an ever more influential role in the definition and control of fundamental social problems such as hunger, disease, environmental decay, and international security. With the growing worldwide saliency of these issues, the global community appears increasingly to have pinned its hopes for the future on science and technology. Not only are scientific knowledge and know-how deemed essential for managing the world's most pressing problems, but science, because of its still potent claims to value-neutrality, promises to provide the only forum where nations can set aside their political and cultural differences in favor of a common, rationalistic approach to problem solving. To "scientize" an issue is at once to assert that there are systematic, discoverable methods for coping with it and to suggest that these approaches can be worked out independently of nationalistic or sectarian interests. The yearning to resolve social problems by appealing to the apolitical authority of science persists, even as accumulating evidence emphasizes the porosity of the membrane that actually separates science from society.

My objective in this paper is to try to reconcile these contradictory impulses about science and technology in the context of international science policy. How can we gracefully come to terms with postmodern views about the relativism of scientific knowledge without rejecting the possibility that science may provide a uniquely effective avenue for harmonizing disparate conceptions about the rights of human beings, their place in nature, and their obligations toward each other and to their planet? I approach this question by first briefly reviewing several strands of scholarship that have revealed a previously unsuspected subjectivity, and a consequent pluralism, in the claims of science about the real world. Second, I discuss the implications of these findings for the relationship between science and public policy. Finally, I attempt to draw some lessons for science policy in the international arena from experiences which thus far have accumulated primarily in the varied national contexts of policy making.

The Deconstruction of Scientific Authority

In everyday talk about science policy, scientific knowledge is generally seen as the answer to problems; decision makers conceive of science as a mechanical component of solid reliability that can be fitted intact into the policy process. It comes as no surprise when senior officials at the US Environmental Protection Agency (EPA) vow "to get the science right" in carrying out the nation's environmental program[1] or when the Commissioner of the Food and Drug Administration turns to an expert committee for recommendations on how to improve the flow of scientific advice into his agency. For many years, a similarly naive optimism marked academic writing about science policy. Nearly two decades of postwar collaboration between American science advisers and their government produced no deeper insight than Harvey Brooks's well-known dictum that science can both act upon policy ("science in policy") and be acted upon by it ("policy for science").[2]

Awareness that there might be unforeseen complexities in the relationship between science and science-based policy was slow to develop. An early contribution was a 1970 essay by the physicist and nuclear expert Alvin Weinberg. Spurred by new and controversial developments in the public management of risky technologies, Weinberg speculated on the implications of policy makers' increasing dependence on inadequate scientific evidence. Questions were asked of science, he noted in a now famous passage, that science was not in a position to answer; Weinberg dubbed these issues "trans-science" and suggested that scientists had a special obligation to "inject discipline and order into the often chaotic trans-scientific debate."[3] But although his essay underscored the problematic nature of the boundary between science and policy, it adhered to a conventionally linear notion of the relationship between the two fields of endeavor. Science, as Weinberg saw it, was still something that could be cleanly done by scientists and factored as needed into policy. The only complication was that pure science was no longer sufficient for solving social problems. Policy makers also needed to ask and resolve a variety of trans-scientific issues with a bearing on public decisions. For these, Weinberg judged the open and adversarial processes of the law to be most appropriate, at least in the legalistic decision-making culture of the United States.

The scientific and technical controversies of the early 1970s, however, brought forth evidence that Weinberg's model was too simple to capture all that was really taking place at the nexus of science and policy. A largely American body of case studies documented the important role that political interests played in the production and interpretation of science for policy purposes.[4] Whether the objective was to site a nuclear power plant, market a new drug or pesticide, or build a new supersonic aircraft, it appeared that the proponents of technology consistently read the evidence of risk or safety differently from its opponents. As long as the science was uncertain – as Weinberg said was always the case when predicting extremely improbable events – the likelihood of objective scientific analysis appeared to be extremely low. Organized interests were always on the alert to give the available information a spin that supported their own demands with respect to science and technology policy.

While political scientists and policy analysts focused mostly on the subordination of science to interests, a string of studies inspired by cultural anthropology argued that interests and preferences had to be grounded in a social context and that social organizations and institutions were therefore a more productive starting point for investigating how science was interpreted under conditions of uncertainty. Why, for example, did expert judgments about environmental degradation and deforestation in the Himalayas differ so radically with respect to such seemingly scientific "facts" as "per capita fuelwood consumption"? Three researchers who addressed this question concluded that the experts' views were conditioned in every case by underlying, socially induced perceptions of the problem. The "facts" that the experts had tried to discover about the Himalayas were so variable and context-bound, in short so irretrievably trans-scientific, that they could not possibly be ascertained through universal models of scientific inquiry. What the experts had to offer in the end were not descriptions of reality in any epistemologically tenable sense, but rather varying interpretations of uncertainty shaped by their own and their informants' local contexts and locally colored world views.[5]

Social organization has also been offered as the explanation for divergences in the public perception of risks from contemporary technologies. Building on a theoretical framework first developed by the anthropologist Mary Douglas, a number of authors have argued that risk perceptions are conditioned by two factors common to all organizations: the strength of a group's boundaries in relation to the rest of society, and the rigidity of the internal rules of prescription or differentiation within the group. Applying this model to the American environmental movement, for example, Douglas and her co-author, the political scientist Aaron Wildavsky, suggested that entrepreneurial cultures, characterized as low on both the grouping and prescriptive dimensions, are generally most open to the risks as well as the benefits of new technologies. By contrast, Douglas and Wildavsky saw strongly grouped, egalitarian cultures as intrinsically risk-averse, because they are able to defend their group's social identity most effectively by reacting against a perceived external threat.[6]

If interests and cultural biases permeate the way people perceive risk, then traces of such bias can be expected to surface in the analysis of scientific evidence purporting to establish that risks exist. Numerous comparative policy studies lend support to this hypothesis. In my own work on chemical regulation in Europe and the United States, which used political rather than social organization as the relevant independent variable, I found systematic differences in the way national regulatory experts interpreted evidence of carcinogenicity from animal and epidemiological studies.[7] Features of political culture, such as the extent and forms of public participation, influenced the reading of science, accounting in many cases for divergent interpretations of the same body of data. The open and adversarial style of US regulation, in particular, exposed the uncertainties in the data, raised questions about the principles of risk assessment, and perpetuated technical debate in a manner that was virtually unknown in Europe. The dynamics of the politics of science as revealed in these studies were remarkably similar to more general patterns of national regulatory politics.[8]

Does the interplay between scientific uncertainty and social institutions or interests fully account for the myriad ways in which science splinters, fragments, and kaleidoscopically rearranges itself in the policy context? Recent work in the sociology of science suggests that a deeper explanation can be found in the means of production of scientific claims. Close observations of science in the making have revealed that the validity of scientific "facts" and "theories" depends on tacitly negotiated, interpretive conventions that are shared among communities of researchers.[9] Science, thus "socially constructed," retains its authoritative status as long as its underlying premises are not scrutinized too closely or with hostile intent. It is, however, always vulnerable to deconstruction, and particularly so in the policy arena, where pressure from competing interest groups and organizational cultures routinely militates against consensus-building or closure around any particular account of "reality."[10]

At the junction between science and policy, even the definition of "science" is open to interpretation and renegotiation. Weinberg, as we saw, identified a bridging domain of trans-science between pure science and pure policy, but his approach failed to recognize that assigning an issue to one or other side of the science–policy boundary can never be a neutral exercise. Labeling an issue as either "science" or "policy" implicitly entails an allocation of power, as has been compellingly illustrated by decades of controversy about the principles of cancer risk assessment in the United

States. Regulatory agencies have tended to stress the policy content of these principles, a move that preserves their discretionary right to articulate and modify them; industry and some segments of the scientific community, by contrast, have characterized the principles as science and pressed to remove their definition and revision to conventional scientific forums. While both sides recognize the importance of scientific uncertainty, regulators construe uncertainty as legitimating policy choice, whereas industry representatives see it as a justification for the exercise of expert judgment. Similar forms of boundary drawing have occurred with respect to the definitions of "peer review" and "risk assessment" as parties with stakes in regulation have sought to emphasize or de-emphasize the "scientific" character of these procedures.[11]

The boundaries of "science" are taken more for granted in cultures with lower levels of social conflict or more entrenched traditions of expert decision making than in the United States. Even in a relatively closed and consensual society, however, controversies occasionally become public enough to force disclosure of the unarticulated, and frequently unscientific, assumptions about nature and society that underpin many supposedly scientific assessments. In the aftermath of Chernobyl, for example, British nuclear experts wrongly estimated the likely uptake of radioactive cesium by plants in northern sheep-farming country with acid, peaty soils. Their scientific models, based on studies in clay soils where cesium is chemically immobilized, had failed to take account of a key ecological variable – a mistake that only came to light when the measured levels of radioactivity exceeded the expert predictions.[12] The model in this case was based on a false presumption of ecological uniformity which might well have been disputed and set aside by the "non-expert" sheep farmers on whose behalf the model was applied. In other instances, expert advisers have incorporated untested and possibly unfounded assumptions about human behavior into their assessments. Unless criticism is institutionalized into the policy process, as it is to a great extent in the United States, deference to the label "science" generally protects such unwarranted exercises of expert judgment from review by knowledgeable publics.

Scientific Pluralism and Normal Politics

The reality of policy-relevant science, then, appears to have succumbed to postmodern attributions of subjectivity, relativism, and context-specificity as surely as the distinctive social realities constructed by contemporary historians, anthropologists, journalists, or photographers.[13] The content of science, and even what constitutes "science" in a given situation, is now seen as lending itself to a multiplicity of interpretations. What implications does this profound shift in 20th century thought hold for the poor policy maker who still seeks to ground governmental decisions in "good science"? Must the effort be abandoned, and policy declared to be a field for politics, untrammeled by claims of knowledge about how the world works? If not, what arguments can we possibly advance for according a special role in policy to scientists and their imperfect ways of knowing reality?

The experience of industrial societies provides incontrovertible evidence, to begin with, that more science does not necessarily make for better, quicker, or more politically acceptable policy. In part, this is because the line between policy and the production of science to guide policy cannot be cleanly drawn; science that is mandated for policy purposes seldom remains sufficiently independent from its context to serve as an entirely credible legitimator of policy.[14] Calls to keep science free from the "taint" of politics are frequently heard, but the social analysis of science has long since established the futility – and perhaps even the folly – of seeking completely context-free knowledge in the making of policy. Since the production and interpretation of science remain contingent on contextual factors, it is hardly surprising that new knowledge does not act predictably or systematically to close debates.[15] Indeed, the evidence from comparative policy shows that expert decisions carry greatest weight in precisely those environments where criticism is most muted – and where decision makers are correspondingly least likely to be pressured into producing new evidence bearing on policy.[16]

Observations about the contingency of knowledge prompted British policy analysts David Collingridge and Colin Reeve to adopt a position of radical skepticism about the power of science to advance rational policy making. The policy process, they contend, always presents an under-critical or an over-critical environment for scientific claims.[17] In the former case, there is already a strong consensus about policy and the addition of new science makes no perceptible difference to the outcome. In the latter, policy adversaries who are separated by serious normative disagreements turn to science for help, but a socially constructed (and hence deconstructible) science again is powerless to deliver them from their political impasse. Instead of accepting science as a neutral arbiter, opposing interests subject each other's scientific evidence to heightened scrutiny, producing endless technical debate. Ironically, the transfer of value conflicts into the scientific arena serves to undermine the authority of science even as it is reaffirming science's power to resolve problematic social issues.

The over-critical model appears on the surface to square well with the experience of US agencies involved in science policy making. The regulation of carcinogenic chemicals at the Environmental Protection Agency (EPA), as noted earlier, provides a case in point. Protracted debates over science and years of apparent stalemate on policy have indeed been commonplace in the EPA's attempts to set standards for chemicals suspected of causing cancer. But the over-critical model does not alone explain why scientific closure has proved so much more elusive in some national contexts than others. Particularly from the standpoint of international science policy, it is important to ask why scientific controversies persist so much more stubbornly in America, for example, than in other industrial countries sharing similar economic and political concerns and confronted by similar gaps in knowledge. To address this issue, we have to look beyond the cognitive structure of science to the institutions and procedures by which science is incorporated into policy. We can then point to specific impulses in American democratic culture – in particular, a commitment to a rationalistic mode of policy criticism – that present a deep dilemma for expert agencies seeking to harness science to the resolution of social problems.

The experience of regulatory politics in America discloses an underlying tension between the transparency that is required in a system of democratic politics and the boundedness (both epistemological and social) that is needed for closure in science. Thus, the obligation to make the administrator's scientific reasoning explicit evolved as the quid pro quo for extraordinary expansions of administrative power during the 1970s. US expert agencies were granted considerable discretion to make decisions that were supported by suggestive but not conclusive scientific evidence, but the price they paid was to give up exclusive control over the interpretation of uncertainty. In an unparalleled move to open up scientific decision making, legislative and judicial decisions combined to ensure that interested parties and, if necessary, the courts could scrutinize every step in the agencies' technical analyses. American jurists in particular were convinced that transparency of reasoning would lead to more effective criticism, and hence in the long run to a better fit between science and policy.

The model of progress that the courts envisaged for policy was very similar to the model of scientific progress offered in a 1942 article by Robert Merton, one of America's foremost sociologists of science: full disclosure and open criticism by peers, procedures that had successfully turned the wheels of science for three centuries, would equally move the policy process along toward a happy convergence of truth and power.[18] As expressed by David Bazelon,[19] an eminent federal appellate judge:

> [D]ecisionmakers should disclose where and why the experts disagree as well as where they concur, and where the information is sketchy as well as complete. Other experts who are steeped in the subject matter – in academe, in government, in industry – *can then evaluate the agency's factual determinations, bring new data to light, or challenge gaps in reasoning.* [Emphasis added.]

Missing from this analysis, however, was any clear acknowledgment of the divergent goals of science and policy and how these might influence the construction of scientific claims relevant to policy. Science, as we have seen, needs a certain level of containment in order to move forward. To be successful, scientists have to accept the theories and claims of their predecessors as a point of departure for building other claims, which, in turn, can serve as building blocks for their successors. The historian of science Thomas Kuhn called this type of activity "normal science" and pointed out that it takes place within a governing "paradigm" that remains stable for long periods of time but can be overthrown by scientific revolutions.[20] More recently, the French sociologist Bruno Latour has noted that scientists need to "black box" certain findings (i.e., to shut them off against overly intrusive criticism) in order to propel forward the overall project of science, which is to build more and more "facts" about the real world.[21]

The scientist's primary rationale for closure (making more facts) ceases to be relevant, however, when science is engaged in policy making. In this context, scientific facts function as a bridge to policy rather than to more facts, and the way is therefore opened for diverse interests to coopt the definition of facts in ways that advance their particular social and political leanings. As the terrain expands from normal science to normal politics, scientists, government officials, labor and industry, public interest groups, and even the news media claim the right to place their own interpretive stamp on science. Advantage can be gained, moreover, not only by advancing one's own account of the "facts," but also by weakening the accounts of others. Thus, procedures that allow for open criticism do indeed "bring new data to light, and challenge gaps in reasoning," as the US courts foresaw, but the commitment to scientific rationality, coupled with the commitment to democratic openness, leads in the policy environment not to enlightened consensus but to a mounting cacophony.

Renegotiating the Boundary of Science and Politics

The picture I have painted thus far of the relationship between science and policy looks bleak indeed. The contingency of knowledge can be overcome, and science can be invoked as an independent support for policy, but only in relatively closed political systems, where the opportunities for effective criticism are largely foreclosed. Such policy environments are "under-critical" chiefly because they are under-inclusive: they systematically exclude viewpoints that could lead to the deconstruction of dominant expert opinions. In more open democratic environments, by contrast, criticism only begets more criticism, with policy stasis as the inevitable result. Once science becomes the property of groups of diverging interest, institutions of government can rarely muster the authority to close off spiraling scientific debate. There are no analogues in the contentious domain of normal politics for instrumental testing of the "truth" of competing claims (e.g., through building a technological artifact) or for the shared communal objectives that promote working closures in normal science.

Confronted by this dilemma, some societies have opted to remain in, or even revert to, a policy framework that restricts the participation of potentially destabilizing critical voices. Such a trend is discernible even in the United States, where public participation in science policy has hitherto achieved its fullest flowering. At the EPA, for example, the influence of external scientific advisory committees has grown since the early 1980s, when the Reagan administration briefly attempted to reduce the power of the agency's Science Advisory Board. The US Congress has mandated from time to time that the EPA should institutionalize an advisory mechanism, seek external peer review, channel research funds through an independent body,[22] or solicit advice from the prestigious National Academy of Sciences. These developments signal that on the American political scene the EPA's own expertise is no longer viewed as sufficient to mediate among conflicting scientific viewpoints. The agency must look to outside bodies, with unassailable claims to impartial scientific authority, in order to validate its own interpretations of uncertain science.

Recent efforts to reform the handling of scientific evidence in the US court system reveal a similar technocratic bent. For much of the last quarter-century, a fairly relaxed standard governed the introduction of expert testimony into legal proceedings. Courts were inclined to admit scientific evidence so long as the risk of confusion or prejudice did not outweigh its potential relevance. Assessing the relative weight and credibility of the evidence was thought to be the responsibility of the jury or other fact-finder. But with the rise of technology-related lawsuits, class actions, and crippling damage awards for major companies, the role of experts in the courtroom has begun to attract growing and adverse attention. Unrestricted access of experts to the jury is seen by segments of the American policy community as an invitation for "bad science" to crowd out the "good," thereby allowing anti-technological sentiments to control the outcomes of legal decision making.[23] Support has emerged at the highest levels of the US government for the proposition that judges should take more care to exclude "fringe" scientific views, so that the authority of "mainstream" and "respectable minority" views can be enhanced.[24] We can see in this proposal another manifestation of a more general cultural trend toward enlarging the power of science to influence the directions of policy.

Efforts to restructure a bounded institutional space for science within the policy process can be defended on the grounds that any system of scientific assessment – including policy advice – needs some bracketing off from society in order to achieve cohesion and credibility. Common standards for interpreting scientific evidence are more likely to evolve when scientists feel united in a shared ethos, such as the public service orientation of an advisory committee, than when they meet as representatives of competing social interests. Interpretive differences, moreover, can be more easily ironed out in the relatively non-adversarial culture of the typical advisory panel than in the confrontational environment of lawsuits or administrative hearings. Regulatory agencies have taken advantage of these characteristics of advisory committees to resolve conflicts at several critical stages in the assessment of policy-relevant science: validation of long-term research strategies; certification of study protocols and analytical methodologies; definition of standards of adequacy for scientific evidence; and approval of inferences from less-than-conclusive studies and experiments.[25]

Attempts to spin off interpretive authority over science from politically accountable governmental agencies to advisory panels, however, may produce new tensions for science, primarily in the form of intensified public scrutiny. Thus, US legislation already requires all advisory committee meetings to be conducted in public, and real or imagined lapses from this mandate frequently trigger enforcement actions by vigilant public interest groups or the news media. The US Congress, too, has enlarged its periodic inquiries into the conduct of advisory committees to include investigations of the political or intellectual biases of individual committees members. Balance in the composition of expert panels has assumed growing importance as a political issue. There is considerable pressure for expert committees to mimic the diversity of the US population, and federal guidelines exist to ensure that women and ethnic minorities are adequately represented on all such bodies.

Allegations of bias and conflicts of interest represent another kind of challenge to expert committees wielding significant decision-making power. In the United States, for example, former members of an EPA advisory panel were accused in one case of violating federal ethics requirements by testifying on behalf of a pesticide company before the panel on which they had served.[26] In another episode, the tobacco industry sought to block the appointment of a particular medical scientist to an EPA panel on the ground that he was not sufficiently "open-minded" about the risks of smoking.[27] Controversies over the health risks of formaldehyde, asbestos, and lead illustrate another kind of exclusionary pattern aimed at challenging established policies. In these cases, scientists whose work had already influenced significant policy commitments found their objectivity or good faith under attack by parties seeking to recapture control over policy through competing accounts of reality. Incidents such as these highlight the vulnerability of the social consensus that protects scientific advice against the intrusive thrust of politics.

While advisory committees represent an undeniably technocratic approach to dealing with political dissension and the contingency of knowledge, a contrasting, apparently democratizing trend can be observed in the growing popularity of technology assessment, which was institutionalized in the United States with the passage of the 1972 Technology Assessment Act, and which later made rapid headway in Europe during the 1980s. Technology assessment initiatives have in common the presumption that technology policy works best when stakeholders are identified in advance and are drawn into the policy making process. Right-to-know laws, such as those enacted in Europe following the Seveso accident and in the United States following the gas leak in Bhopal, also place a high value on integrating the public earlier and more fully into science and technology policy. These provisions presuppose that a certain level of shared information is necessary in order for the public to recognize and effectively protect itself against risks from industry. The preoccupation with ideas such as "risk communication" and "public understanding of science" on both sides of the Atlantic similarly reflects an emergent philosophy that sharing knowledge is the most effective means of creating a receptive public environment for science and technology.

On closer inspection, however, these moves toward democratization in science and technology policy appear no less technocratic in inspiration than the strategy of containing the interpretive flexibility of science within specially appointed advisory committees. The irony in the democratizing strategy is that state planners apparently assume that the public, once it is fully informed, will come to value the benefits of technological advancement more than they fear its possible deficiencies. But the state can ensure such results only by carefully controlling or manipulating the knowledge that it offers to share with the public. It has been noted, for example, that in the European context the public's "right" to know is construed by the state as coextensive with the public's "need" to know. The Seveso directive recognized no generalized public right to information; European governments agreed to make available only as much information as they thought the public needed to know for purposes of self-protection.[28] In the absence of such centralized control, more information could reasonably be expected to lead to a pluralization of views, as various segments of the public impose their particular social constructions on the contingencies inherent in the available scientific information.

The Internationalization of Science Policy

How do the foregoing observations carry over into the international arena, where forces of economic and environmental interdependence are creating accelerating pressure for supra-national approaches to science and technology policy? The question has profound implications which academics and decision makers have barely begun to address, and the literature on international science policy accordingly lacks the theoretical sophistication that is evident in many studies focusing on national and comparative policy contexts. I will argue, in particular, that there is an important discrepancy between the postmodern account of policy-relevant science that I have presented above and the positivist or empiricist strain evident in much current writing concerning the role of science in international environmental policy. One consequence is that the degree of consensus in environmental sciences, as well as of scientists' power to influence policy, have been exaggerated, while the problem of inadequate participation in international science and technology policy has received disproportionately little attention.

The first satellite pictures of the earth freely suspended in space not only ushered in a new era for space exploration but also gave rise to a new ecological paradigm for the scientific study of the environment. Here was visually irrefutable proof of the finiteness of the place we inhabit, the interconnectedness of its living systems, and the futility of looking beyond the planet for solutions to planetary problems. The concept of the biosphere gained prominence and the urge to understand it more completely led to authoritative new approaches in both the natural and social sciences. National funding priorities shifted toward fields that tried to make sense of large systems or connections among systems, such as ecology, climatology, chaos theory, and geography. Even the Gaia hypothesis won grudging respect from scientists who a few years ago had dismissed it as the brainchild of a religious crank or mystic. Across the environmental sciences there was a new emphasis on research that would bridge existing disciplinary divides and produce insights into the complex and ill-understood workings of planetary phenomena. In short, the systems analytic perspective seemed to come into its own, with regained vitality, in the context of efforts by human beings to understand their environment.

In policy analysis, as well, a new discourse emerged to encompass the unsettling image of spaceship earth, a discourse that tried to temper the freshly acquired sense of human limitations with hopes for a common scientific understanding and international cooperation. A seminal report from the World Commission on Environment and Development[29] captured both the terminal loss of the frontier and the promise of enhanced control:

> From space, we see a small and fragile ball dominated not by human activity and edifice but by a pattern of clouds, oceans, greenery, and soils. Humanity's inability to fit its activities into that pattern is changing planetary systems fundamentally. Many such changes are accompanied by life-threatening hazards, from environmental degradation to nuclear destruction. These new realities, from which there is no escape, must be recognized – and managed.

In an influential discursive move, the Commission adopted the term "sustainable development" to designate the possibility of overcoming resource limitations through human enterprise. These two words seemed to sum up and yet transcend the contradictions of life and growth on a bounded planet. They suggested that the indefinite survival of the human species on planet earth could be assured through a simple marriage of science and rational stewardship of the earth's resources.

Although a few scientists and policy analysts questioned the capacity of science to operationalize the notion of sustainability, most policy makers began looking to the sciences (as they historically have done) to define both problems and solutions in the global environment. Scientific knowledge has been credited with creating the momentum for worldwide cutbacks on the production and use of ozone depleting chemicals, as well as for multi-lateral discussions promoting wider consensus on greenhouse gases, biodiversity, and deforestation. Scientists themselves are identified by some analysts as primary agents of policy change, using the power of knowledge to move national governments toward decisions that they could never have reached under accepted models of rational choice. According to one view current in the literature, "epistemic communities" of scientists, actuated by common professional norms and shared, holistic definitions of environmental problems, are successfully setting the agenda for international negotiations and driving their own governments toward agreements.[30] Here, then, we have a reversion to the classical (that is, pre-Weinberg) model of science policy, which envisioned a united front of scientists engaged in "speaking truth to power." In this latter-day formulation, a new cadre of scientific high priests, equipped with the potent paradigm of ecological interconnectedness, are taking control of policy, thereby uniting truth and power in benevolent harmony.

The problem with this optimistic assessment is that it disregards virtually everything we know about the contingency and plurality of knowledge and the interaction between knowledge and politics. The picture of scientific and policy consensus that dominates recent work on international environmental policy seems immediately suspect from the standpoint of social studies of science or interpretive policy studies. Important questions are missing or obscured. Why, one wishes to know, has the ecological viewpoint so easily gained ascendancy in environmental policy circles? Is there really a strong consensus about the causes of global environmental problems such as ozone depletion and global warming, and, if so, what accounts for the surprisingly low levels of conflict on such momentous questions? Who are the participants in the world's suddenly powerful epistemic communities, and how have they managed to overcome the problems of criticism and deconstruction that have consistently plagued their counterparts in national frameworks of science and technology policy? Does the apparent epistemic consensus on some environmental issues betoken inadequate levels of participation, and will the entry of more states into global scientific conversations increase the level of controversy in the same ways as participation by interest groups?

Once embarked on these skeptical lines of inquiry, one does not have to look far to notice that the consensus on the scientific causes of global environmental problems may be much less durable than it seems. The on-going North–South debate over population provides a telling example. To many scientists in advanced industrial societies, the concept of a finite biosphere inescapably suggests the need for stringent controls on human population. Yet Third World environmental analysts and activists generally reject the idea that current population levels pose a critical threat to achieving sustainable development. Natural resources in the Third World, so their argument goes, are sufficient to support the ecologically balanced life-styles of the world's poor, provided that ways can be found to eliminate the dislocations induced by arbitrary and inefficient state management schemes in developing countries and by non-sustainable consumption patterns elsewhere in the world. The "problem" from this perspective is not how to limit the numbers of the poor, but how to improve their access to nature's still bountiful resources. Scientists in the North offer a quite different definition of the problem, focusing on the environmental damage that will be caused if populous Third World countries emulate, and eventually attain, the resource-consumption patterns of the North.

That the same "scientific" concepts – here "overpopulation" and "sustainable development" – can give rise to two such diametrically opposed problem definitions provides strong evidence of their socially constructed character. Clearly, the widely accepted ecological paradigm that underlies emerging ideas of sustainability is not by itself enough to determine whether the "right" definition of the population issue is "too many people" or "inequitable access to resources". To create global convergence on such explosive topics as population, we need to build not merely a common body of knowledge about how the world works (that is, epistemic communities), but also communal norms about what kind of world we want and how human beings should relate to the world's other living and non-living systems.

A Role for IIASA

What does this review of science and technology policy from national and international perspectives imply for IIASA in the coming decades? Two strategies are imaginable, with the riskier one carrying the greater prospects for long-term satisfaction. An apparently safe option for IIASA would be to accept at face value the invitation to systems analysis that is implicit in the new ecological thinking about the global environment. With support for systemic approaches running high in both scientific and political circles, IIASA could choose to present itself as a provider of integrated, culturally unbiased research and policy advice on the "big" environmental issues of our time: population, loss of species, deforestation, desertification, climate change, and environmental refugees. There is a strong demand in policy circles for more "scientific" methods of predicting the physical and social impacts of global change, as well as an enduring belief that modeling on a grand scale holds the keys to universal understanding. It should take no daring act of creative imagination to design a program that meets these perceptions and perceived needs. Few policy makers have the courage to withstand the lure of numbers, and IIASA's international network could easily summon up the shamans of economic and environmental science to answer to almost every uncertainty.

The second, and more challenging, strategy would be to take the apparent givens of the physical and social worlds and turn them into questions leading to vastly different forms of inquiry. In this approach, the ecosystemic paradigm and the conceptual subcategories traditionally associated with it become starting points for looking more closely at their constitutive elements rather than for reductionist system-building. Instead of refining the existing analytical models, which often flatten out detail and diversity, this strategy requires us first to ask which are the right problems and how we should recognize them. Is the problem too many people or unequal access to food or fuel? Is it cutting down trees in subsistence economies or subsidizing the milk prices of the already rich, thereby increasing the demand for unforested grazing lands? Is it how to accommodate refugees fleeing forms of repression that no law at present recognizes or how to achieve an ecologically benign redistribution of human populations to ensure more efficient use of nature's resources?

Pursuing these alternate lines of inquiry is sure to open up epistemological and moral questions that have not yet caught the attention of most global change analysts. How can we identify and evaluate the different belief systems that support competing definitions of the "same" problem, particularly when one side claims to be the more "scientific"? What should be the objectives of the inquiry: merely to reveal the basis for discrepant problem definitions or also to reconcile them in some fashion? If the latter, then where will the means of reconciliation be found – in claims of superior expertise or in knowledge tempered by more participatory forms of politics? If science is accorded a special role in ironing out cross-national or cross-cultural differences (as it surely will be), then in cases of disagreement whose "science" should be taken as controlling?

These deconstructive approaches to looking at global problems may, ironically, point toward "systems" of a kind that are not currently recognized in any traditional branch of science, although they have a growing reality in the social studies of science and technology. I speak of the heterogeneous systems – composed of people, practices, social rules, laws of nature, artifacts, and the like – that govern our increasingly complex existence. Where should we look for the "causes" of deforestation in the Amazon basin, the rising incidence of brain or skin cancer in parts of the world, or the industrial catastrophes that have occurred in various Third World countries? If a clod be washed away by the sea in the Bay of Bengal, the cause today may truly lie in the social life of Europe or North America. Yet one may not see the connecting threads without drawing on as yet unsystematic bodies of knowledge or engaging in inquiry that cuts orthogonally across more orthodox approaches to systems analysis.

Adopting my second strategy would undoubtedly require IIASA to expand its participation beyond the countries it has served for 20 years, as well as to seek out resources that are not earmarked for conventional programs of study. At the same time, the best analytic orientation for this wider membership may well be to begin by thinking small. Microstudies of microproblems may offer more illuminating results than the analysis of full-blown systems that turn out in the end to contain neither the causes nor the solutions that really matter. Qualitative research will be needed to give meaning to quantitative analysis. But the dangers that humanity faces call for fresh academic endeavor. In science policy, as in life, it is the road not taken that often holds the richer promise.

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CHAPTER 6

Redrawing the Boundaries Between Science and Politics: Toward a Postmodern Version of Speaking Truth to Power

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In Chapter 5 (Pluralism and Convergence in National and International Science Policy) Sheila Jasanoff traces the roots of the widespread intellectual unease that surrounds a lot of scientific inquiry and technological practice at present. She highlights the more subtle strain of skepticism that has been added through the recent work performed in social studies of science and technology, with their emphasis upon the in-built sociality of science and the role played by social negotiations in the construction of scientific knowledge. She maintains that the distance between scientific and political processes is narrowing. In extreme cases this may lead to endemic conflicts in society becoming re-enacted in public controversies that erupt over scientific and technological issues. The overall aim of her chapter is to invite us to consider ways of reconciling the recent, more relativistic conception of science and its deconstruction with the unique effectiveness that scientific knowledge holds with regard to what she identifies as an urgent goal for the future, namely, "to harmonize disparate conceptions about the rights of human beings, their place in nature, and their obligation toward each other and to their planet." This entails a reconciliation of political pluralism with a new definition of the relationship between science and public policy, both in a national and international context.

Some of the key words that Sheila Jasanoff puts on our agenda are: subjectivity; deconstruction; pluralism and postmodernism, rather than what we have so far understood as scientific realism; objectivity; and instrumental scientific rationality or social engineering. The main issue addressed in her chapter is how the authority of science, by now socially deconstructed, might meet political pluralism, and the new demands that are addressed by a policy-oriented or policy-relevant "science for public policy". On reading her chapter, which accords well with other accounts, I was struck by the observation, in retrospect, of how rapidly the processes she describes under the rubric of deconstruction have proceeded. From A. Weinberg's prescient article in 1970, where he introduced the notion of "trans-science", 20 years later we have barely moved to a situation where the insistence upon such boundaries separating different roles for scientists appears hopelessly inadequate. Only about eight years ago an international forum on Science for Public Policy was held at IIASA where many of the pressing issues of today were raised, yet at the time they may have appeared as mere warnings of possible trends to come (Brooks and Cooper, 1987).

So what has happened that has caused such a dramatic redefinition of the relationship between science and policy? What we have witnessed is, first of all, the rapid (and some may say overdue) demise of the old model of rationality that was believed to be inherent both in the policy process and in the way a purported scientific rationality in the form of policy advice could be fed into it. The demise of this model is related to other profound changes, notably those that have altered the relationship between market forces and the state. In Europe, especially, the all-powerful welfare state, in the glorious three postwar decades in which it reigned supreme, saw the rise of powerful and effective alliances between modernizing elites and scientific establishments, including the social sciences, all eager to advise policy makers. The welfare state was built on a belief in rational planning, with a definite scientific underpinning. One of its fundamental premises was an as yet largely unclouded vision of further human betterment which would be achieved with the help of science and technology, while negative consequences either were denied or kept invisible.

Since then, much has changed. Not only have these political alliances fragmented, but the former broad consensus of a "societal project" of major, future-oriented proportions has been shattered. In addition, the once-powerful state has lost much of its former capacity to control events and ideologies that favor such control. Political majorities have become difficult to maintain and demagogical elements pervasive. A process of societal desolidarization has set in, for which the belief in progressive forces of further technological innovation along with the distribution of wealth thus created can no longer compensate. After the fall of the Communist regimes in the countries of Eastern Europe, science and technology run the risk of being perceived as having been deeply involved with the old totalitarian order, giving rise, perhaps, to new waves of anti-science. In the USA, where the state never played the central role it did in continental Europe, other dispersive forces have come to the fore, aided by an adversarial, political legal culture that relies heavily on the judicial system to confront societal conflicts and that allows "junk science" to enter the courtrooms. Everywhere the growth of legislation containing a scientific or technical dimension is enormous, while the political mechanisms for solving disagreements and the ensuing conflicts have undoubtedly been lagging behind.

Other factors come to mind that have made an equal contribution to the demise of the old conception of science for public policy and have led to a greater demand for the public accountability of science and technology. In many ways one might argue [as I have done elsewhere (Nowotny, 1990)] that science has become much more like other institutions in modern society: in its organization and work setting, in its moral standing and the norms held by its members, and in its affinity toward (some would say corruption by) economic and political influence. From this it is easy to make a more discomforting conclusion: if science is not so special, it has no grounds upon which it can claim privileged status as far as its funding base and political support is concerned. It is but a short step to being treated like any other institution that functions to serve society. It is but another short step for science to become affected by this process of "societal normalization": science would then not only be held accountable for achieving results "worth their money", but could rapidly lose its claims to a higher form of rationality and the higher cognitive status and authority that goes with it.

In de-mystifying science and technology in society at large, and in deconstructing the claims upon which scientific knowledge are based, social studies of science and technology have played but an epiphenomenal role. While the new approaches toward studying "science in the making" have made a decisive contribution by elucidating the social nature of science and technology and by showing their profound in-built sociality, it is too simple to make social studies of science and technology responsible for attempting to subvert the authority of the natural sciences while offering little in return. While it is understandable that natural scientists react with irritation to what they see as the subversive and de-mystifying results of much social analysis, it would amount to a gross overestimation of the potential impact of any social science research to attribute the actual process of de-legitimation of science largely, or even in part, to such analysis. If we look to the power of ideas and the cultural influence they can command to change the general outlook of a society, then we have to take into account the much wider currents flowing in the ever-changing cultural sea of society.

The decisive turn, then, is from a modern society to a new formation under the label of "postmodernity". Postmodernism is far from being merely a cultural fad or an intellectual game invented by and for Parisian intellectuals. Recently, Thomas Hughes, the eminent historian of technology, spoke about "post-modern technology". What he meant were the radically altered organizational conditions of production, as well as the altered conditions of intellectual and social creativity under which technologies are being created today. They include modes of financing as much as altered styles of corporate management – the new patterns in which the originators of science and technology interact constantly with potential users: configurations of people and things and hardware and software that are all rearranged in a novel, postmodern form (Hughes, forthcoming).

One of the premises of postmodernism is the deconstruction of any central authority. Due to the increase in complexity, no single, centrally organized locus can be in control any more. The postmodern condition entails fragmentation and the loss of any central perspective. In line with Sheila Jasanoff, I will argue that it also enables new forms of local action and allows for contingencies: it entails entirely new possibilities of "just connect" through multiple configurations via which creative new interlinkages are being networked. Far from being only a "bundle of ill-defined concepts and methods", the postmodern Zeitgeist has seeped into the social fabric of society, it has affected, for better or worse, the relationships between a former centralized locus of power and authority and those who are connected to it. In essence, postmodernism constitutes a solution that has evolved in response to a greatly increased societal complexity. Is it surprising that science, as a central authority in our highly industrialized societies, is also affected by the radical shift toward postmodernity?

So far, the response from the natural scientific establishment has been largely one of bewilderment and defense. The first overriding impulse was, and still is, to cling to sharply defined boundaries between science and society, while allowing the intermediate and intermediary space that exists between them to grow. In this intermediate space, a pragmatic model of managerial science for public policy has been allowed to operate, yet its effectiveness is contingent upon policy contexts that have become much more unpredictable. Sheila Jasanoff detects a definite technocratic bent in the ongoing renegotiations of the boundary separating science and politics, and she believes, if I read her correctly, that this trend is likely to succeed. In the USA, she sees a more general tendency toward reducing the power of lay perspectives to influence the direction of science and technology policy, partly as a reaction toward the role of experts in the courtroom. She has some fine things to say about the importance of "closure" in the production of scientific knowledge, which loses its rationale once scientific knowledge switches context and becomes policy-relevant. She points out that both scientists and the state have a stake in representing results as "science" so as to protect them against renewed destruction – all of which, presumably, will strengthen the return to a more technocratic bent. However, this may turn out be no easy road of return.

Another scholar, Yaron Ezrahi, who has attentively observed science in the framework of the transformation of contemporary democracy is convinced that the growing public distrust of science and technology is more a symptom of the changing conception of politics than of science and technology per se. However, if this is the case, it nevertheless has radical consequences for science and technology too. While major economic, military, or social crises are likely to revive the more conventional rhetoric of scientific realism, the criticism of "pleasing illusions", and appeals to science and technology, Ezrahi believes that, for the time being, "stagecraft", the art of eloquent, edifying, and politically effective gestures, is the supreme technique of "statecraft". However, he also cautions that the "descent of Icarus", the de-legitimation of grand social and political engineering and the decline of instrumental rationality in the context of public affairs, does not necessarily represent a return to darkness. Postmodern politics and postmodern science will have to face their own respective limits (Ezrahi, 1990).

The situation in which postmodern politics and science are currently facing their limits while renegotiating their boundaries is perhaps nowhere as manifest and as urgent as where environmental sciences meet environmental policies. The very term of "science for public policy" ceases to be meaningful if science is taken to imply a relatively closed, self-contained set of knowledge which is supposed to provide guidelines for action. The complexity of the phenomena and the problems associated with them, their truly global nature, and their interconnectedness continue to raise some fundamental questions about scientific determinancy, uncertainty, and the relationship between scientific knowledge and policy advice and action. The ongoing, threatening degradation of the environment defies any simple, causal approach to solutions. Instead of "solutions", the best we can hope for is "management", instead of a simplistic notion of growth, sustainability as a collectively sustained process has yet to be learned by individuals and nations alike. Multiple local actions, all embedded in economic and social arrangements, and global environmental effects are interlinked in intractable ways, while global action, the aim of reaching international consensus and binding agreements, is confronted with obstacles that thrive on scientific uncertainties.

Historically, it can be said that science-based industry and industrialized science began when, in the second half of the 19th century, academic science moved into specially set-up industrial research laboratories. Today, we witness another historical turning point – that of environmental sciences moving out into society. This makes them open to new claims of societal access, participation, and accountability. A whole new set of issues is awaiting recognition and some form of incorporation into science: the environmental rights of citizens, a new "contract" with nature, intergenerational rights, communal rights for common property, such as the atmosphere and the oceans, the setting up of environmental codes of conduct, and the definition of the responsibilities of scientists. Science is being challenged to become "vernacular" – conversant with mature citizens and willing to accede to certain of their legitimate demands. Science is being asked to share knowledge and information, to set up monitoring processes with these mandates in mind and share their results. The management of sustainable development calls for a new kind of cooperation between natural science and social science, but this management process can only hope to succeed if it does not fall into either of the two old traps: becoming science infiltrated by politics or science aloof from society.

I have reached the last part of Sheila Jasanoff's paper where she turns to the internationalization of science policy. Jasanoff argues that there is an important discrepancy between the postmodern account of policy-relevant science and the positivist or empiricist strain evident in much of the current literature about the role of science in international environmental policy. She believes that the degree of consensus among environmental scientists has been vastly exaggerated, while the problem of inadequate participation in international science and technology policy has received disproportionately little attention. She detects an unfounded optimism in accounts that celebrate a united front of scientists engaged in "speaking truth to power", which is equally evident in those accounts that seek to unite truth and power in what she calls "the benevolent harmony of the paradigm of ecological interconnectedness".

She asks the pertinent question of why – given the skeptical stance that social studies of science and technology teach us – the ecological viewpoint has so easily gained ascendancy in environmental policy circles and whether there is really a strong scientific consensus about issues such as ozone depletion and global warming. Why are scientists – as epistemic communities – working in the international framework apparently immune to the problems of deconstruction and criticism that plague their counterparts within national frameworks of science and technology policy? Is this consensus not more apparent than real, a mask that can easily be undone if one gets down to the real political issues, such as the North–South debate over population issues that is defined differently by scientists working in the North and those working in the South?

The answers to these and other apparent contradictions lie, I believe, in the following: scientists working on global environmental problems have no choice but to become truly trans-scientific. As the first genuine trans-scientists they are constantly moving over scientific terrain: but the terrain's epistemic core is intrinsically policy-relevant, and hence is bound to reach out beyond merely scientific issues. Knowledge cannot be separated from action any more: knowledge, action, and power meet in one. As trans-scientists, they occupy plural roles. They sometimes act as advisers to their governments and form part of their nation's delegation in political–environmental summit meetings and other international conferences. At the same time, they are highly expert in their own right and form part of the epistemic community of world environmental scientists. They understand that problem definitions are contingent upon context, which includes the policy context. They have learned to practice dual or plural loyalties – to science, which always means international, universalistic knowledge, and to their governments or employers as well. The apparent ease with which they move between these realms, the dexterity with which they change hats and cross boundaries, makes them truly postmodern. They speak to each other in one language and to those in power in a different one, tinged sometimes by national allegiance, while still professing the internationalism of science. Some of them have also learned to speak a third, fourth, or fifth language, among them the one that Tim O'Riordan has called the vernacular language of science, namely the ability to address lay people and to involve them in environmental science as it reaches out to the public. Speaking truth to power has become a truly postmodern affair.

Of course, this does not imply that international science and international science policy are immune to the redrawing of boundaries between science and politics. Rather, they are already part of it. Yet, as is too patently obvious, the international political community of this planet is growing together only slowly. Despite the urgency of action, international concerted action is – as one would expect – much more difficult to obtain. On the other hand, whatever international action can be achieved can also be interpreted as an encouraging sign in moving onwards on what is definitely a long road ahead. In the sea of international political dissension, international scientific consensus strengthens not only the position of scientists themselves vis-à-vis their national governments, but vis-à-vis political power in general. In contrast, those in national politics, often faced with contradictory scientific evidence in regulatory matters, can use scientific international consensus to emphasize or de-emphasize national policy goals. Hence the interest of all parties in colluding with what Jasanoff describes as the surprising ease with which the ecological viewpoint has gained ascendency in environmental policy circles.

Of course, there are other forces at work as well. We should not see speaking truth to power solely in Machiavellian terms. There are genuine concerns that result from realizing the global nature of the problems and the hazardous situation in which humanity is rapidly finding itself on this planet. There is the challenge of sustainability and the redefinition of our way of seeing the world that comes with it. There have been historical gestalt switches in the past in the societal definition of the fundamental relationship between society and nature: but never before has the challenge been perceived so globally and never before has there been such a powerful array of scientific and technological means at our disposal. We are faced by an apparent lack of societal consensus on how to proceed and how fast, while realizing only slowly that the two may be connected. It is the nature of science itself that has changed. I believe this is the final point stressed by Jasanoff when she speaks about IIASA's second option. The deconstructive approach – once it is also accepted by natural scientists and all those who mistakenly still believe they can clearly separate "hard" facts from "soft" values, or keep the boundaries that separate science from society watertight – constitutes a powerful intellectual tool of the new societal self-reflexivity. It allows us to come to terms with the "postmodern" condition that permeates society, while at the same time giving rise to postmodern science and postmodern technology. It allows us to see the heterogeneity of systems and in systems – and yet to perceive some patterns of order emerging from apparent chaos.

I therefore join Sheila Jasanoff in her wise words of advice to IIASA to be more daring and to embark on a road that, while accepting deconstruction, nevertheless aims at utilizing the knowledge and self-reflexivity thus gained to make political pluralism a workable solution. Much will depend on the robustness and adaptability of the intermediary organizations that are springing up everywhere, and their success in renegotiating the boundaries between science and politics. Much will also depend upon the authenticity with which the intermediary space is open to citizens' demands, even if openness will not necessarily bring with it political consensus. If we are to go for political pluralism, it may well be true that only "divided we stand" (Schwarz and Thompson, 1990). In the end, there cannot be only one solution, for this very pluralism implies that science and society will have to find – and accept – many different configurations in which their boundaries are redrawn.

If there is a lesson to be learned, it is that science will be able to maintain its claims toward a higher form of cognitive rationality only if it is able to incorporate and accommodate sufficient elements of the ongoing societal discourse – for the simple reason that science is no longer immune to society.

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CHAPTER 7

Decision Analysis and Support, and the Study of Developmental Challenges

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IIASA's Role in Systems and Decision Analysis

The history of IIASA contributions to the field of theory and methodology of systems and decision analysis would actually require a separate book [a paper on this theme was written 10 years ago, see Wierzbicki and Young (1981)].There are several areas of this field in which IIASA research – done mostly in the Systems and Decision Sciences Program, but often in cooperation with other IIASA programs and projects – achieved international recognition. For example, this research contributed significantly to the increase of knowledge in areas like non-smooth optimization, uncertainty in mathematical modeling, non-linear dynamics, and multiple-criteria decision analysis and support.

The essential reason for IIASA's effectiveness, both in theoretical or methodological and in applied or substantive fields of research, is the multi-cultural and interdisciplinary cross-fertilization background. We are well aware that, in addition to universal scientific values, many perspectives emerge from the diversity of national cultures. On the other hand, the issue of achieving a global unity of goals while preserving cultural diversity is one of the most difficult challenges of the contemporary world, which we can observe in contemporary politics. At IIASA, different outlooks and traditions brought from various member countries confronted each other and melted together – often not without conflicts, but with consequences that should be measured by the roles of IIASA alumni around the world rather than by scientific publications alone.

Yet there is still another, more basic level of IIASA contributions: such a melting pot as IIASA helps to lead to a deeper development of new basic concepts which are necessary for a better understanding of the increasingly complex world. This will be illustrated in more detail for specific examples: we should stress here that contributions at this level cannot be achieved without not only multi-cultural, but also interdisciplinary synthesis. Thus, whatever IIASA's future might be, it should not concentrate solely on one disciplinary field.

Decision Analysis and Support

The question of how decisions are made and how to support decision processes has been investigated in several, originally separate, theoretical fields such as decision and game theory, operations research, optimization theory, control and dynamic systems theory, mathematical modeling, computer science, artificial intelligence, and expert systems. There has also been an antithesis to all these analytical approaches – the soft systems approach related to general systems theory, stressing holism and synergy as opposed to reductionism in systems analysis: see, for example, Grauer *et al.* (1985). Over a decade ago – see, for example, Bonczek *et al.* (1981) and Andriole (1989) – the growing power of computer technology and its practical applications led to another development: the emergence of decision support systems (DSSs) as opposed to earlier data processing systems (DPSs).

Originally, DSSs were developed as a practical, ad hoc collection of "any and all data, information, expertise and activities that contribute to option selection." Today, due to a development in which IIASA played a considerable role, the concept of DSSs is interpreted more broadly: they are computerized systems that support their users in the rational organization and conduct of a decision process (or its selected phases) and contain, in addition to a data base, a pertinent knowledge representation in the form of models of decision situations, as well as appropriate algorithms for using these models. However, the original concentration on practical aspects of decision support has led to possibly the most important dimension of the contemporary definition of DSSs: the sovereign position of the user – see, for example, Andriole (1989). The user can be a decision maker, an expert or an analyst, an ordinary person working in an office on a well-defined task that might benefit from decision support, or even a group of people with varied expertise and decision authority. In any of these cases, a DSS must not replace the user in their sovereign decision making, it should only help them in:

- A rational organization of the decision process.
- Processing information customized for selected situations and phases of this process.
- Enabling them to draw upon expertise and knowledge encoded in the models included in the system and to use various algorithms for the evaluation of options and alternative decisions.

In this conceptual and methodological development, IIASA has played a significant role. We realized that the substantive, applied programs and projects at IIASA represent a unique source of expertise on various aspects of environmental, economic, and developmental processes, often encoded in mathematical models, but usually transcending such models and consisting of a much more diversified type of knowledge than typically represented in artificial intelligence or expert systems. Human knowledge can only partially be represented by models of the logical type: various analytical models and the intuition related to their interpretation constitute not only a more flexible, but also a much broader part of knowledge.

The question was how could we develop methodological tools to incorporate this type of knowledge in DSSs. In accordance with IIASA tradition – see, for example, Keeney and Raiffa (1976) – we concentrated on a multi-attribute approach. However, in order to stress the sovereign role of the user, we did not concentrate on the issue of option selection alone and used multi-objective optimization as a tool for the flexible analysis of models and for organizing efficient interaction between the user and the DSS. This was the essence of the reference point method, developed at IIASA in the early 1980s, starting with Wierzbicki (1980, 1982) and Kallio *et al.* (1980). From the beginning, this method stressed the combined use of models, which were provided by substantive projects, with multi-objective methods for their analysis and for their interaction with the user, which were supplied by methodological projects. Applications at IIASA were related to several areas such as sectorial economic policies, future energy supply scenarios (see Grauer *et al.*, 1982), the natural gas trade in Europe (see Messner, 1985), as well as several other topics [see, for example, Strubegger (1985)].

During the 1980s, methods similar or essentially equivalent to the reference point approach were internationally recognized as the most versatile tools for multi-objective model analysis: see Mikhalevich and Volkovich (1982), Steuer and Choo (1983), Nakayama and Sawaragi (1984), Korhonen and Laakso (1986), and Seo and Sakawa (1988). The reason for this evolution was that methods of this class can be treated as the generalizations of several older methods of multi-objective analysis, such as compromise programming by Zeleny (1973), surrogate trade-off methods by Haimes and Hall (1974), the maximal effectiveness principle by Khomenyuk (1977), and, especially, goal programming – see Charnes and Cooper (1977) and Ignizio (1978) – while preserving the advantages of these older methods but overcoming their drawbacks.

For applications in DSSs, reference point methods have a specific, desirable property that stresses the sovereignty of the user: the continuous controllability of the selection of efficient solutions by the user, see Wierzbicki (1986). The development of these methods was continued, among others, by the Polish community of researchers in DSSs cooperating with IIASA. Several prototype DSSs using reference point methods were implemented and tested on diverse applications – including variants of DIDAS, DINAS, HYBRID, and other systems, see Lewandowski and Wierzbicki (1989). Such systems were later also called aspiration based. Contributions to multiple-criteria bargaining and group decision support were made [see Bronisz *et al.* (1989) and Wierzbicki (1990)]: partly in cooperation with IIASA's project on negotiations. Diverse approaches to representing uncertainty or imprecision in decision analysis, mathematical modeling, and optimization, such as set-valued or inverse methods [see, for example, Kurzhanski (1986)], stochastic optimization with its multi-objective aspects [see, for example, Ruszczynski (forthcoming)], fuzzy sets [see, for example, Kacprzyk and Fredrizzi (1988) and Slowinski and Teghem (1990)] or rough sets (see Pawlak, forthcoming), have been studied either in IIASA or in Poland. We perceived also that while mathematical modeling and simulation are established disciplines, their applications to decision support have specific aspects which require considerable methodological advancement (Wierzbicki, forthcoming; Wessels, forthcoming).

Thus, while the original work on decision support tended to neglect methodology, IIASA-related activities resulted in its substantial theoretical and conceptual advancement. Various phases of decision processes were better understood. An essential distinction between preferential versus substantive models representing knowledge in DSSs was made and the use of diverse classes of analytical models of knowledge investigated (see Wierzbicki, forthcoming). New conceptual challenges resulted from the dispute about the role of human intuition in decision making [see, for example, Dreyfus and Dreyfus (1986)]: it appears now that there are possibilities of a rational study of intuitive decision making that would help to construct DSSs which could enhance the intuition of the sovereign user.

Most of the concepts and developments indicated above can be stated in mathematical terms. We comment here only on some related basic concepts and ideas. Although the basic concepts of multiple-criteria optimization are sufficiently well described, for example, in Sawaragi *et al.* (1985), Yu (1985), Steuer (1986), Seo and Sakawa (1988), it turns out that an essential role in this field is played by conical separation theorems. While separation theorems are universally used for the derivation of necessary conditions of optimality in single-objective optimization, their application is usually restricted to convex cases and linear separating functions. The nature of multi-objective optimization, however, is such that we should separate a set of attainable outcomes from a cone: it is then possible to select non-linear separating functions with conical level-sets. Such functions are called order-consistent, achievement scalarizing functions (see Wierzbicki 1986, 1990) and have several advantages. They result in a very general characterization of efficient (multi-objectively optimal) solutions, including non-convex, discrete, dynamic, and other infinite-dimensional cases. They are parameterized in a natural way by reference points that express the aspiration or reservation levels of a user of a DSS or a decision maker. By changing the reference points, the user can continuously control the selection of efficient decision outcomes – which would not be possible if linear scalarizing functions were used. The use of an achievement scalarizing function with conical level-sets is equivalent to applying exact penalty functions to soft constraints representing reservation levels for various objectives: thus, such an approach generalizes several former approaches to multi-objective optimization.

The concept of conical separation can also be applied to problems with uncertainty expressed either by probabilistic formulations or by fuzzy sets. In the latter case [see, for example, Zadeh (1965) and Granat and Wierzbicki (1992)], it can be assumed that a decision maker – a user of a DSS – might be imprecise about his preferences concerning decision outcomes, but can specify and modify fuzzy membership functions expressing the degree of his/her satisfaction with the outcome values. The aggregation of such membership functions for several objectives might then be obtained through an achievement scalarizing function. Such an approach is particularly helpful when organizing a graphical interaction with a DSS.

Another application of the concept of conical separation is related to the characterization of non-cooperative solutions in multiple-criteria games. While the main body of game theory deals with multiple criteria under the assumptions that they can be either scalarized by a given value or utility function or represented by additional players, there are many cases when such assumptions are not justified. This was often pointed out, for example, by Blackwell (1956), Contini (1966), Yu (1973), and Zeleny (1976). Although the basic concepts of a multi-objective version of game theory were defined and analyzed by Bergstresser and Yu (1977), this theory was not fully developed subsequently. The application of conical separation theorems – see Wierzbicki (1990) – results in a full characterization of non-cooperative solutions to such games, even in non-convex cases.

The analysis of non-cooperative solutions in multi-objective games can be applied to studying processes of conflict escalation. The computation of an equilibrium in a single-objective game is based on the assumption that the preferences and pay-off functions of all players are known to each other. In a multi-objective formulation of a game we must still assume that at least the nature of objectives and and some additional information (for example, aspirations or reference points) are known. However, in real-life situations even this information would be strategically guarded: any player would have to guess and assume the objectives and reference points of other players. If some of the players guessed incorrectly, their decisions would not correspond to any equilibrium and the outcomes of such decisions might be worse than expected. In a repetitive game, this would lead to revised assessments of the preferences of other players, with a psychological tendency to blame them and to retaliate: the original lack of information and the inability to communicate is the real cause. Retaliation, or even seemingly rational responses based on inadequate information, usually leads to a process of conflict escalation. Special experimental multi-objective games can be devised in order to study such processes and the adaptability of players when avoiding conflict escalation.

The Study of Developmental Challenges

We are living at the turn not only of the millennium, but also of the epoch of civilization. The epoch that started with the Industrial Revolution and the Enlightenment era almost three centuries ago is coming to its end, having produced not only advances in science and technology, but also ideological strifes between communism and capitalism, or extreme nationalism and globalism, worldwide wars and threats to global environment, and demographic explosions and green revolutions – all without precedence in human history. The next epoch is variously characterized as the post-industrial, service, or information society, or the epoch of Informed Reason: see, for example, Toffler (1980) and Wierzbicki (1983, 1987). In these publications, it was often stressed that an essential aspect of this transition is a deep change in the basic concepts of perceiving reality. Without a deeper understanding of these concepts, we will not be able to meet the developmental challenges of the coming epoch.

Yet these are usually perceived on the conceptual basis of the old, not the new epoch. Thus, important aspects of these challenges are often neglected, as in Fukuyama (1992) and related discussions where it was not even noticed that the fall of communism was accelerated by the emergence of the information society. Similarly, the difficulties of the transition of Central and Eastern European countries to a market economy are perceived through the focus of Smithonian concepts, which are adequate for industrial capitalism, but the transition is more difficult precisely because the people in these countries have aspirations to become members of the information society, not the old industrial one.

Advances in science and technology during the last century resulted in a change in the basic concepts of understanding reality – time, space, cause and effect relations, uncertainty and chaos, information processing and knowledge representation, the nature of human decisions, and the possibility of supporting them by computers. While this change originally resulted from developments in physics (the relativity of space and time), in telecommunications, and automatic control (the concept of feedback that made obsolete the mechanical understanding of cause and effect), further stages of this change are related to computer science, as well as to developments in systems and decision sciences.

We shall consider here briefly some of the concepts mentioned above: the chaotic behavior of complex systems, the value of information, the formation of aspirations and the possibility of a cusp in a dynamic system, and the traps of rationality and the evolution of cooperation, as well as their possible applications in studying developmental challenges.

The concept of chaotic behavior [see, for example, Gleick (1987)] is based on the observation that even a relatively simple deterministic mathematical model of a dynamic system, if it is nonlinear and contains sufficiently strong feedback, can produce behavior that is extremely sensitive to microscopic changes in parameters or initial conditions and is sufficiently complex to be practically unpredictable. Actually, this was known some time before the study of chaos. For example, we cannot produce truly indeterministic behavior in computers, and all random number generators are actually quasi-random: they are in fact chaotic generators. Contemporary physics, although it frequently uses these chaotic generators in computers, has not yet fully assimilated the concepts of feedback and chaos. The uncertainty principle is still interpreted as a reason to believe that the universe is indeterministic: it may be felt that there is no sense in discussing this issue when a simple, deterministic model can represent uncertain behavior equally as well as an indeterministic one. The concept of chaos, however, is even less well known, and might have more profound consequences for social philosophy.

Social philosophies of the industrial epoch – be they Marxist or Smithonian – are based on mechanistic models of society, where an individual action is lost in the statistical average. However, if we perceive society through the perspective of chaotic behavior, a tremendous responsibility descends upon the individual. In critically sensitive circumstances, an individual's action can have decisive consequences for the future of the world (which is actually well known in history, but social philosophies tended to overlook this fact). Naturally, the individual will be guided by his own interest (the fall of communism has taught us that it is foolish to assume otherwise). However, studies of decision analysis teach us (see Axelrod, 1984; Rapoport, 1989) that in a sensitive situation – for example, in a situation of conflict – the individual often modifies his own interest by invoking a set of basic values which, if properly chosen, might prevent conflict escalation.

Naturally, we might also ask the question: how common are such sensitive situations that could affect the future of the world? A time of civilization transition is generally sensitive and such critical situations might occur quite frequently. Besides, the frequency of such situations might increase in the next epoch. This is related to the next concept – the role and value of information.

A loaf of bread must be divided and either eaten or saved for the next day; a book can be read by many without losing value. Obviously, if the information component is a decisive factor in the value of products of the information age, we must develop new economic principles. The traditional answer is to establish a market for information: it is true that we must guard intellectual property and rights in order to have a sound economic system in the coming epoch. However, there are several catches in this simplified reasoning: an information market has various peculiarities, since an economic game with information content has neither zero nor constant sum. Moreover, in truly sensitive situations, access to appropriate information might have impacts quite beyond its market value. Information can be either properly or improperly used (e.g., by a researcher finding a cure for AIDS or by a nuclear terrorist). Thus, some information should be common property and some must be restricted: which set of basic values should be used to decide which is the case?

Science thrives on free information exchange: the developed countries should help the developing ones by providing information that might be essential for preventing a further growth of discrepancies in the world. Unless we treat the issue of information value more deeply and seriously, it might well become the main source of social tensions in the coming epoch. A *Manifesto for an Information Age* has already been written (Grundner, 1989).

Up until this point we have discussed the possible future importance of the concepts mentioned above, but they might also be essential for understanding what is happening at present. The value of information can be illustrated by a simple example of a recent controversy concerning scientific and educational policy in Poland. In the process of transformation toward a democratic market society, the Polish parliament decided that the allocation of budgetary funds for scientific research should be supervised by a democratically elected representation of scientists and must employ competitive allocation mechanisms similar to systems used by the National Science Foundation in the USA for granting support for research.

Accordingly, a new law was passed, elections held and the Committee for Scientific Research constituted. (It has a rather complicated structure, but the Committee proper consists of 12 elected representatives of the scientific community and 6 representatives of the government – ministers of cabinet rank). Having been elected to this body, the author of this chapter – as a specialist in decision analysis and support – spent much of his time improving the details of the corresponding competitive allocation mechanisms.

However, the Committee of Scientific Research also has an important role in formulating the overall policy for science and education in Poland – and a controversy soon escalated between the members from the liberal government and the elected members of this body. All agreed on the necessity of competitive mechanisms, but the liberal government also came to the conclusion that the system of science and education in Poland is overexpanded and, in this time of budgetary shortages, should be the first source of savings. What we needed was rather simple information – international comparisons of the size and funding of various parts of the system, well interpreted and understood (because of the international diversification of the structures of such systems, it is necessary to decide which elements are comparable). Such information actually existed in Poland – but the government members did not pay attention to it, rather they listened to the opinions of their foreign advisers which can be summarized as follows: "since you have such good scientific and educational results in Poland, it is clear that the system must be overexpanded." This resulted in budgets for science being cut by half and by one third for education – which caused a crisis that threatens all the reforms that have been initiated.

Intuitive opinions might be not only valid, but sometimes more valuable than those based on analysis. However, experts must ensure that their opinions (no matter whether intuitive or analytic) reflect adequate information. The proportion of GNP allocated for science and research in Poland (around 1.2% for several years, less than 1% last year and less than 0.5% after budgetary cuts) is several times smaller than, say, in Hungary or Czechoslovakia, similarly for education. Hence, the system is certainly not overexpanded in financial terms. In terms of scientific personnel, the part of the system consisting of the basic research institutes of the Polish Academy of Sciences and industrial research institutes is slightly overexpanded: but, including universities, the overall number of researchers in Poland relative to population is one of the smallest in Europe. This is due to an undersized and elitist system of higher education in Poland that teaches only about 10% of the age cohort to the level of a high-quality, five-year study leading uniformly to a masters degree. This scholarization index of 10% is again several times smaller than in Hungary or Czechoslovakia. We cannot sustain democratic reforms without substantially increasing this index, shortening the number of years of study, and diversifying the university system. Therefore, the transformation of this system needs more, rather than less, financial support. This information succeeded in convincing the government – which had changed in the meantime and become christian-nationalist – that it should not decrease (there is no possibility of actually increasing) the funding, but the crisis is not over yet.

Perhaps more significantly, the understanding of current developmental challenges can be improved by using the concept of aspiration formation, introduced by H. Simon (1957) in the satisficing theory of decision making. [Actually, the methodology of reference points in decision support can be considered as an extension of this theory to a quasi-satisficing approach: see, for example, Lewandowski and Wierzbicki (1989).] If we have a computerized model of a developmental process that includes some decision variables, we do not need to analyze future scenarios by making assumptions about which decisions will be made. Much more consistently, we can ask experts what, in their opinion, will be the development of socioeconomic aspirations, quantified in the form of some aspiration trajectories for selected development indices. A multi-criteria decision support system can then solve the inverse simulation problem by computing the necessary decisions to come as close as possible to the specified aspirations (or, if possible, to exceed them) and ascertaining the corresponding attainable trajectories for the selected indices. By changing aspiration trajectories, we can generate alternative development scenarios. This approach has been used by several applied projects at IIASA, in cooperation with the SDS program: for example, when analyzing forestry sector policies, energy supply scenarios, natural gas trade, etc.

In its essence, this approach assumes that a society finds ways (e.g., by acting through its democratic institutions) to institute policies that help to come as close to the dominant social aspirations as is possible in given physical, economic, and environmental conditions. These conditions are often represented by a computerized model, called a substantive model because it encodes expert knowledge on the substantive limitations to development – as opposed to preferential models that represent social preferences, which, in this approach, are simply approximated using the concept of aspiration trajectories (and order-consistent achievement functions).

However, sometimes such substantive models of complex developmental issues are not available. This is the case in the soft analysis of developmental challenges, usually performed by an interdisciplinary committee of experts. The organization of work along traditional lines in such a committee is often quite difficult. In the Committee of Future Studies, "Poland 2000" (in 1989 reorganized and renamed "Poland in the XXI Century"), of the Polish Academy of Sciences, we found that the concept of aspiration scenarios is also quite useful for soft analysis. The committee discusses and chooses what might be alternative scenarios of dominant social aspirations, while keeping in mind that actual development scenarios could be quite different to the aspirations. Appointed subcommittees then address the question of what would be the actual development in selected areas for each of the assumed aspiration scenarios. The most difficult is the last phase: this is a joint discussion and the formation of conclusions about what the attainable development scenarios corresponding to alternative aspiration scenarios would be. The results of such a study are then reported. An example is Wierzbicki (1991).

The events of the last few years in Eastern Europe indicate that, in times of change, another related concept might be important – that of the aspiration gap. If the difference between the social aspirations and the attainable development becomes too large, social tensions grow and can result in either a cusp (an essential change of development trajectory related to the phenomenon of bifurcation in non-linear dynamics) or even unpredictable, chaotic behavior related, for example, to regional or national conflicts.

When reverting to old nationalist values in times of global change, people fall into rationality traps that can be avoided only by the evolution of cooperation: these concepts are well studied in contemporary decision analysis (see Axelrod, 1984; Rapoport, 1989), but unfortunately not sufficiently well known to the popular audience. In order to accelerate such evolution of cooperation, it is necessary to promote new values: however, which ones?

We have already indicated several times the importance of this question. It appears that values universally acceptable to humanity might be derived from the evident threats to the global ecosphere. The emergence of the concept of Gaia is a very significant intellectual development. Instead of conclusions to this chapter, I would like to propose a further intellectual challenge: perhaps somebody should attempt to write a report to Gaia, not only stressing the necessary basic components of the value of global responsibility, but also postulating and analyzing such a new set of values.

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PART IV

Models to Say What the Future Holds

CHAPTER 8

A Linear Model for Environment and Development

Lawrence R. Klein

The Layout of an Economic Model

The general *linear* model of an economic system can be described by the following compact design:

$$A(L)y_t + B(L)x_t = \Gamma(L)e_t \tag{8.1}$$

$$\Theta(L)x_t = \Phi(L)u_t \, . \tag{8.2}$$

There is a counterpart non-linear model, which is indeed more widely applicable and also used, but the points that I want to deal with in this chapter can be more conveniently dealt with in the linear framework, with closed form expressions. Non-linearities are very important for understanding the economy, but not necessarily for showing its interdisciplinary aspects.

In the language of econometrics, the column vectors in equations (8.1) and (8.2) are defined as follows: y_t is the n-element column vector of endogenous (dependent) variables; x_t is the m-element column vector of exogenous (independent) variables; and e_t and u_t are, respectively, the n- and m-element column vectors of random disturbance affecting system performance.

The matrices have elements that are polynomials in the operator L. For example, the typical element of $A(L)$ is

$$\alpha_{ij}(L) = \alpha_{ij0} + \alpha_{ij1}L + \alpha_{ij2}L^2 + \ldots + \alpha_{ijp}L^p \ .$$

The operator L is a lag displacement operator such that

$$L^i y_t = y_{t-i} \ .$$

The matrix $A(L)$ is square and $||a_{ij0}||$ is non-singular. The matrix $\Theta(L)$ enjoys analogous properties. The matrix $B(L)$ is rectangular (nxm); $\Gamma(L)$ and $\Phi(L)$ are diagonal.

The important aspect of equations (8.1) and (8.2) for the purposes of this chapter is the block triangularity of the $(n+m)$ equation system. Implicitly, x_t has influence on y_t, but there is no feedback from y_t to x_t ; this is the essence of the concept of exogeneity in economics. In some investigations it is assumed that e_t and u_t are independent, but this is only a simplification and is not essential.

The structure of equations (8.1) and (8.2), without feedback from y_t to x_t, means that the economist pays less than complete attention to the process that generates x_t: weather and climate are left to the meteorologists; population dynamics are left to the demographers; crop yields are left to the agronomists; "animal spirits" are left to the social psychologists; etc. The intention of this chapter is to address the broadening of the economist's perspective in order to try to integrate their analyses more closely into those of related disciplines.

In effect, the system defined by equations (8.1) and (8.2) can be broken down into a traditional economic model, given by equation (8.1), and "another" model for the treatment of the exogenous variables. The economist, in general, pays precious little attention to the latter, even to the point of neglecting some economic feedback that could have or should have been taken into account. The problem is one of defining an exogenous variable in the context of an economic system.

The independence of elements of e_t and u_t imply the corresponding independence of elements of x_t and e_t, since

$$\Theta(L)x_t e_t' = \Phi(L)u_t e_t' \ .$$

The serial covariances of u_t and e_t are also assumed to vanish. This is the strict definition of an exogenous variable, but under less restrictive conditions concerning the relationship between e_t and u_t the x_t terms can be treated as though they, or variables closely related to them, are exogenous. There are other definitions of causality and exogeneity in econometrics, but I believe that the time-honored concept that I have described above is the most meaningful one for the purpose of exploring the expansion of the domain of economic modeling and analysis.

The unit of observation used in equations (8.1) and (8.2) is an undefined time period. Many other observation units – the firm, the household, the person, the political entity – could be used as well, but there are some important effects on the concept of exogeneity that are related to the length of the time period unit. The finer the time unit, the less interdependent are the components of y_t, and the more recursive these components (of which there are several) become. This means that the $A(L)$ matrix may also be triangular or block triangular.

Economists often distinguish between two types of reasoning – short-term and long-term. For many kinds of contemporary problems, especially in well-organized, efficient markets that are served by telecommunication devices, time variation is practically *continuous*. Feed-forward dominates *feedback* in such situations. There is more exogeneity or "predeterminedness" in short-term systems, in units of days, weeks, or months, say, than in longer-term systems that deal with quarters, semesters, years, or decades. In longer periods of time, there is much greater scope for the appearance of feedback, particularly from the economy to phenomena from other disciplines. The broader the scope of interdependence becomes, the fewer the number of elements in x_t. To a large extent, this chapter will be concerned with feedback effects over long time-periods of elements of y_t on what has been traditionally embodied in x_t.

These ideas do not rule out short-term feedback effects across disciplines, but such feedback will be less familiar and not easy to handle. In very short-term analysis in which economists are closely watching and monitoring the intricate twists and turns of the business cycle, indexes of personal attitudes are used in order to gauge the subjective feelings of consumers toward spending, income movements, or price movements. These are useful indicators of behavior over short time-periods of a few weeks and are determined from responses to questions posed in replicated sample surveys. If, however, we economists should want to try to extend the useful life of such pieces of information, we must try to explain the subjective responses in terms of objective, measurable phenomena that lend themselves to extrapolation. This, in my opinion, is a fruitful and constructive way to introduce subjective expectations into economics and to treat them as endogenous variables. Expectation concepts have a long history in economic analysis and in formal modeling, but their implementation requires careful attention to the techniques of survey sampling and to the associated disciplines of sociology and psychology. It is highly unlikely that such issues can be satisfactorily treated by economics alone.[1]

For longer-term analysis, one of the most studied areas of interdisciplinary research is in the relationship between economics and demography. The Reverend Thomas Malthus postulated the simplest kind of joint economic–demographic model, and its very simplicity made it very attractive, yet it pitifully fails to pass validation tests, except possibly in sub-Saharan Africa. Its main virtue is in calling attention to the need for a linkage between two disciplines and in showing how deeply one must go into the two subjects involved in order to obtain credible results, i.e., results that show promise of passing validation tests.

Two examples of models that go significantly beyond Malthus' contribution, yet which are still far short of what is needed, can be found in the macroeconomics literature of the 1950s and 1960s. Stefan Valavanis-Vail introduced endogenous population in a growth model of the United States based on quinquennial data (for overlapping decades) from the macroeconomic accounts of the 19th and 20th centuries, prepared by Simon Kuznets. Valavanis-Vail relied on population size to capture the effects of population growth on long-term economic evolution, but he also tried to explain the components of the identity[2]

$$N_t = N_{t-1}(1 + b_t - d_t) + NI_t \,. \tag{8.3}$$

His definitions were as follows: N_t is the population (stock) at time t; b_t is the average birth rate during period t; d_t is the average death rate during period t; and NI_t is the net immigration (flow) during period t.

He then tried to establish estimation equations for b_t as a function of national income per capita and its rate of change, and d_t as either an exogenous variable or a declining function of t. He did not contribute toward the estimation of an equation for NI_t, but many researchers have investigated such equations in terms of institutional restraints and international income differentials. Obviously, one can go far in the study and development of usable equations for b_t, d_t, and NI_t. However, at least Valavanis-Vail elevated the discussion to a new plane some 40 years ago.

A second provocative paper that attracted a great deal of attention during the early 1960s was Richard Easterlin's consideration of the baby boom in terms of the macrodynamic economics underlying Kuznets' ideas about long swings.[3] Easterlin deplored economists' treatment of demographic phenomena in the following words:

> At the risk of generalizing too freely, it would be fair to say that the typical treatment of population growth in economic theories is as an exogenous variable, whose movement is given by demographers.

He showed how demographic projections can be invalidated by cyclical swings in birth rates when the projections are based on unchanging or monotonically changing birth rates, no matter how detailed the historical birth information may be. He argued that the baby boom could be interpreted in terms of Kuznets' analysis of economic performance over relatively long periods of time. He did not build a formal mathematical–statistical model, but one could, of course, do that.

Demographic modeling, when more carefully integrated with economic modeling, makes use of age, sex, and other distributional categories. Income distributions are one type of closely related distribution and they, in turn, use some of the demographic categories in more refined analysis. Income distributions can be graduated and studied, both descriptively and analytically, by economic variables alone, but good projections will certainly have to take input from politics, sociology, and demographics. Average measures, such as Gini ratios or income class–cohort type measures, can be used in econometric models as endogenous variables. The movement of microeconomic income distributions through time can be used, but a more manageable approach that could yield some useful results at a more aggregative level is to try to generate class (relative) frequencies of income as functions of demographic and various macroeconomic magnitudes through time.[4]

The discussion so far has dealt largely, but not entirely, with national economies, without bringing in explicit international linkages among them. The economic side of national security opens up many possibilities for interdisciplinary research. Military or defense expenditure is usually assumed to be the most obvious of exogenous variables in economics, apart from weather or other natural forces. Non-military spending by government is also often assumed to be exogenous, but that classification is subject to doubt. There is less doubt, probably even no doubt among some economists, about the exogeneity of defense spending. President Reagan used to say, in response to critics who cited defense spending as a cause of the US federal deficit, that a country first decides how much defense is needed and then figures out how to pay for it and how to fit other government activities in line with it.

That attitude would seem to make US defense spending exogenous. However, the political strategist Lewis Richardson has put forward the action–reaction model of the arms race, in which any one country's defense spending (and entire military establishment) is chosen in response to partners' and adversaries' expenditures. On a world scale, such a system seemed to fit the international data set well when the NATO and Warsaw Treaty Organization (WTO) countries were locked in an arms race.[5] In fact, such a model has been used in tandem with the world model of project LINK to endogenize both military and non-military government spending up to the period of the disintegration of the WTO. According to the Richardson model,

$$DF_{it} = \sum_{k=0}^{p} \sum_{j=1}^{n} \alpha_{ijk} DF_{jt-k} + e_{it} \ , \tag{8.4}$$

where identifying restrictions are selectively imposed on α_{ijk}. On a somewhat cruder level, total government spending is made to depend on defense spending, so that

$$G_{it} = f_i(DF_{it}) + u_{it} \ . \tag{8.5}$$

This crudely echoes the views of former President Reagan's critics that large-scale defense spending governed the size of total government spending on goods and services. Many transfer payments, however, that are not included in G_t also contribute significantly to the government budget and deficit. These are called the "entitlements". Some entitlements, however, are in G_{it}. Careful consideration of these and other non-defense outlays can do much to improve the estimation of G_{it} and public transfers, but the political theorizing of Richardson and his followers has also led to interesting results for international model building.

At a more technical level, defense strategists can contribute many ideas on the endogenous treatment of military spending which may be coordinated with an international model such as LINK.

Another technical area is the interface between technology, engineering, science, and economics, as in environmental protection and energy use. There are many actual and potential examples in this field, but one that is at present attracting much attention is the study of the "greenhouse effect" because of concern about CO_2 emissions, largely from the burning of fossil fuels in energy delivery.

In another combination with project LINK, an energy model (the Trace Gas Accounting System, TGAS) has been made mathematically compatible so that the two systems simultaneously generate estimates of prices of energy items, the production of energy, the emission of CO_2, and the feedback to the world economy in 79 linked models for different countries or regional groupings.[6] Environmental problems often cross borders. This is especially true of CO_2 emissions; so an international model that is not too simplistic at a global level, as are models couched in world aggregates, or on too much of a regional plane, is needed in order to capture the international linkages among countries at the economic and environmental levels simultaneously. This is the intention of the interdependent combination of LINK and TGAS. The layout is depicted in *Figure 8.1*.

The use of the two models in feedback interaction is of some interest in itself, but the system is put to a substantive use, namely to study the effects of a carbon tax that aims to reduce emissions. Carbon taxes varying from \$28 to \$42 (1988 prices) per ton of CO_2 emissions in different industrial countries are assumed to be phased linearly over the period 1992–1995. The price increase quite naturally translates into higher inflation and reduced GNP growth, with slightly higher unemployment. It is then shown, in further scenarios, how some of these perverse effects can be mitigated through recycling tax revenues. At the expense of only a little more inflation, the output losses can be eliminated through policies of monetary accommodation. These results are worked out for individual countries and are also extended to an optimal control algorithm.

This is a very flexible methodology that can be extended to many kinds of scenarios, but it is mainly of interest in the present context as an example of an effective combination of international macroeconomics with environmental engineering. There are many other possibilities for fruitful combinations of economics with, for example, technical studies of water delivery (presently under consideration in the Middle East), energy, nuclear fallout, and other areas of collaboration.

Mention has been made of the political analysis of variables that are often classified as exogenous. One of the frequently cited applications is associated with the introduction of reaction functions into macroeconometric models. Consider the implementation of monetary policy. Conventional econometric models place key monetary variables in the exogenous category. These are such variables as, for example, the fixing of a central bank's discount rate, reserve requirement ratios behind deposits, or open market operations that affect available reserves. These variables can either be assigned assumed values on the basis of political judgment, or they can be

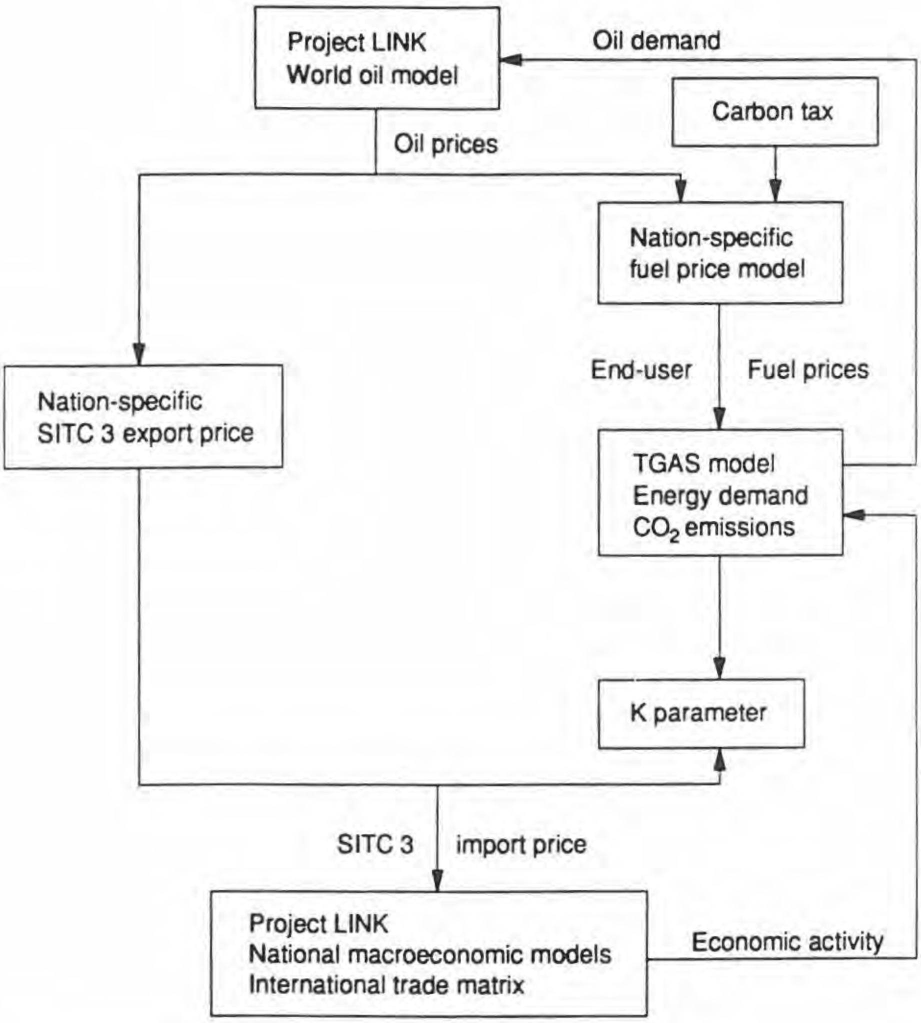

Figure 8.1. Layout of the combination of LINK and TGAS. [The K parameter is the increase in the price of fossil fuel (oil, coal, gas: averaged) resulting from a carbon tax.]

fixed by formulas that show the reactions of authorities to economic performance indicators in relation to accepted targets such as full employment, non-accelerating inflation rates, ratios of trade or budget imbalances to GDP, or analogous magnitudes. When performance reports indicate clearly that the economy is missing its target, monetary reactions are set in motion, and the degree of reaction depends on the deviation of key variables from their targets.

This treatment of politico-economic decision making is not undesirable per se, but the choice of a reaction function is arbitrary because it reflects the decision-making process of a small number of people. The choice must reflect what *they* want and are willing to do. It cannot be made optimal in an objective sense by appealing to control-theory methods because that theory cannot tell us what the objective function is for central bankers or those people that they serve in the political hierarchy. Also, it cannot be sensibly estimated from historical data because it has little or no statistical basis. The observation of the behavior of a few people - literally a handful - over a limited-duration political regime cannot give an acceptable statistical estimate of a relationship. One needs a large sample, transcending many political regimes and involving thousands (*or more*) of people replicating their decisions frequently. This kind of sample does not exist, nor can it legitimately be expected to exist. Nevertheless, for each political body a particular objective function can be put into a model to determine monetary decisions, either optimally or descriptively, and the results can be documented. This has some interest but does not really solve the politico-economic problem of setting monetary policy.

A Generalized Model or Satellite System

It is asking a great deal to expect an econometrician to supply an all-purpose model - one that can be used for whatever occasion may occur. Generality is not bad, in itself, and my rule is to construct the largest model that can be adequately managed to cover a variety of problems. This is what has motivated the structure of the LINK model, which now has more than 25,000 equations that must be solved simultaneously, and is supplied by enormous data files that are updated as quickly as possible – say monthly. More individual countries will be added on a regular basis. Some additions are being forced upon us by the break-up of the USSR; others are to incorporate neglected countries that are small or that are outside the normal orbits of economic discourse (Vietnam, for example). The commodity detail in the country-by-country trade matrix is being expanded; international capital flows and services are being introduced; debt accounting has already been introduced; etc. No matter how far we go in this direction, it will not be possible to be ready, without further work, to analyze atmospheric pollution, delivery of water to desert areas, the arms race, and other interesting important problems.

A natural technique is to append satellite models that can be placed in full feedback mode with the LINK system. In the discussion about simulations of the effects of a carbon tax (in the previous section), the TGAS model is a satellite system to the general LINK system. The satellite shows in some detail how CO_2 is generated by economic activity and also how prices or other valuations are generated in this part of the economy. These variables from the satellite system are then related as directly as possible to corresponding variables in the general economic (LINK) system. The economic model (LINK) and the environmental satellite model (TGAS) are then solved as one large, interdependent system. This process works well, but is tedious in the sense that a fresh satellite must be built for every essentially different investigation that is proposed. Not only is this tedious, but it also slows down the presentation of results. A question is posed, and then the research investigator says that the provision of an answer must await the construction of a satellite model, which can take several weeks or months.

Some judicious mixture of large, general purpose models combined with a satellite system is the practical approach, but models are getting ever larger in order to be able to cope with many fresh problems as they arise. The area of energy modeling is a case in point. At the time of the first oil shock, October 1973, practically no general economic model, covering the economy as a whole, had a detailed enough model of energy supply and use to be able to respond fully to the oil embargo and immediate jump in prices. It so happened that those of us working with the large version of the Wharton Model, combining an input–output model with a macroeconometric model, had been warned repeatedly by oil company economists that the United States would have to resort to large-scale imports of oil in order to satisfy growing energy needs. We had the quantity aspect right, but not the price aspects, which were woefully pegged to price increases for crude oil of 5 cents per barrel, annually.

By using the input–output structure, which had an explicit energy row/column, we were able to predict the onset of recession within three to four weeks of the imposition of the embargo. What is more important, we were able to extend this result to the onset of a synchronized world recession through use of the LINK system, which had an explicit energy level in the set of world trade matrices by commodity category.

While we had judged the quantitative effects very well, we were too low on price. Once OPEC prices started to rise, we projected very high general price levels in documented gatherings of economists who were trying to decipher the unusual situation into which the world had been thrust, but even our high-estimate prices were too low.

Before the onset of the second oil shock in 1979–1980, we had built energy subsector models into our systems more fully so that we were prepared with a sufficiently detailed model to interpret the consequences of the Iranian Revolution within days of its taking place.

While the problems of modeling the energy sector were met by incorporating more elaborate energy detail into macroeconometric models, we did not have enough detail to anticipate the effects of CO_2 emissions or other environmental problems before they were noticed. We had to rely on the construction of satellite models for dealing with environmental problems, and this is likely to be the case for most of the unforeseen problems that are yet to be visited upon us.

The combination of input–output systems with macroeconometric models is now a routine procedure, but the input–output model by itself, no matter how detailed its sectoral disaggregation, will not be able to make adequate projections of prices, stocks, trade flows, and effects on financial/credit markets. The combined model that covers all the accounts in the SNA framework is needed for meeting the tasks ahead.[7] It is important to have a good size input–output system in the full model of the SNA, but the point is that the input–output system cannot solve the whole problem; it can at best contribute to the improved treatment of the production sector and to the understanding of price formation, but it is incomplete by itself. However, it does provide many entry or connecting points at which total macroeconometric systems can be introduced and at which satellite systems can be attached. When input–output systems were used alone to interpret the oil shock of 1973 in the very early stages of analysis, they often overestimated the depressing effects on the economy because they did not depict the high degree of substitution of processes and inputs that were to accompany the wide swings in relative prices. In other words, such systems are necessary, but not sufficient, for the tasks in hand. They have the beneficial feature in the present context, however, of bringing together, in the best applications, both technologists and economists.

Some Specific Interdisciplinary Investigations

There are some recent studies, in addition to the carbon tax investigation described earlier, that point to the realization of interdisciplinary research gains. First, let us consider a popular topic of current interest, namely, the aging of Japan.

There is widespread admiration for Japan's economic performance since 1950. Many countries, in both the developed and developing parts of the world, would like to emulate Japan's success. There are also many complaints about some of Japan's economic practices which seem unfair to outsiders. Japanese economists have pointed out that Japan did not have an easy time rising from the ashes of World War II and Hiroshima/Nagasaki, that they worked hard to reach their present status, and that they face a difficult problem ahead.

Birth rates were low in Japan after a baby-boom period, and population growth was very modest, contributing to the realization of extraordinary output growth – both total and per capita. Many years of low fertility and high longevity have finally resulted in a high fraction of elderly people. At present, the average number of children that a Japanese woman expects to have is 1.53 (a record low, realized in 1990). At the same time, Japan matched Iceland for the record of the highest life expectancy at birth (81 years for females and 76 years for males, in 1986).

The conventional measures of dependency – total dependency and elderly dependency – are shown in *Figures 8.2* to *8.11*, using various UN population projections. *Figures 8.2* and *8.7* refer specifically to Japan. Economic dependency ratios for Japan are shown in *Figure 8.12*. In Japan, there was a period of quite low dependency from the early 1960s until the present time. This was a period of extraordinary economic progress for Japan. During this time, the total dependency ratio given by

$$\frac{\text{population } (0-14) + (65 \text{ and over})}{\text{population } (15-64)} \tag{8.6}$$

had an average value which was lower than that of either Germany or the United States, for example. These are major economic competitors. In the period ahead, however, Japan's dependency statistics indicate a very sharp increase in dependency ratio and higher values for several years than in either Germany or the United States.

Japanese statistics are now being refined to switch those estimated to be at work from the numerator of equation (8.6) to the denominator, and those estimated to be not at work from the denominator to the numerator, to get a better measure of the people not at work who must be supported by those at work. These revised calculations show an entirely different dependency situation. The rise in the total dependency ratio becomes so moderate when labor-force participation is taken into account that it appears that

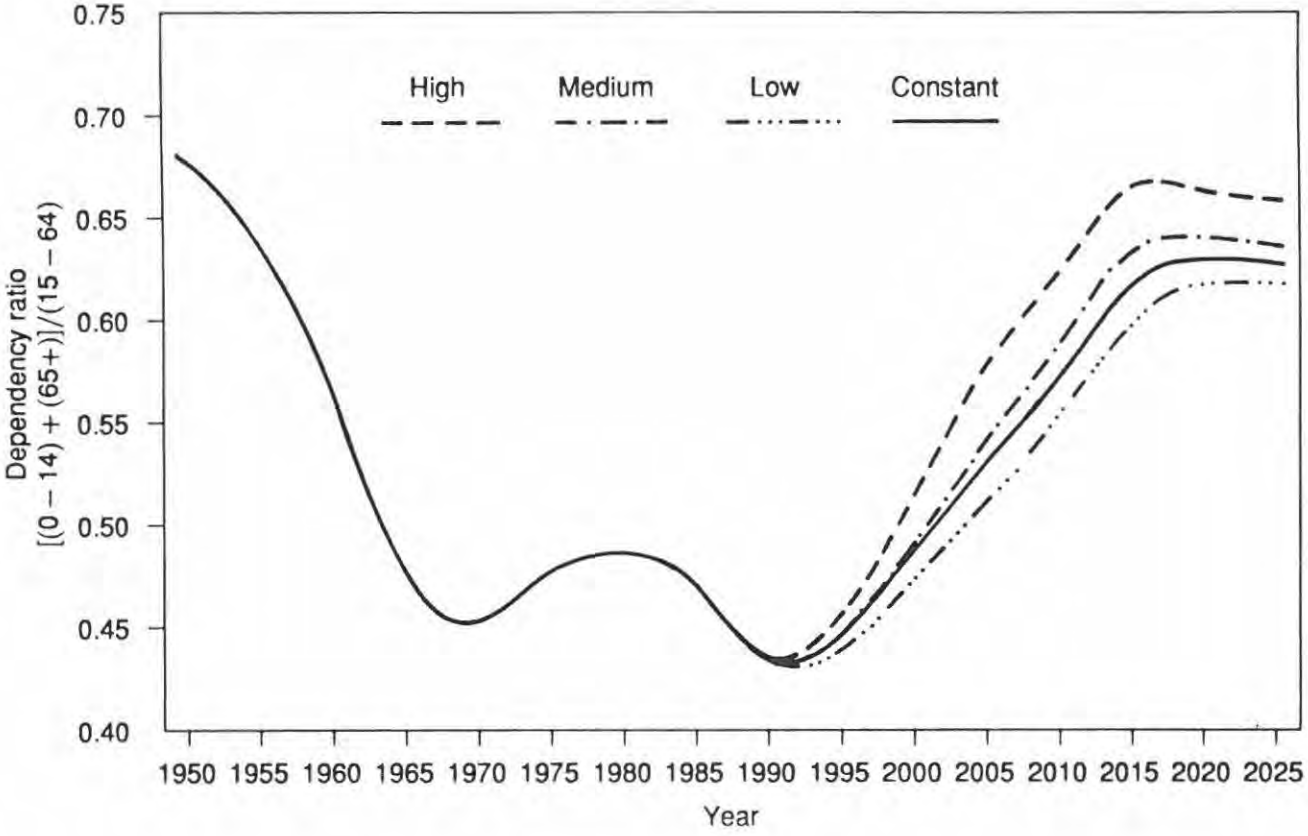

Figure 8.2. Dependency ratios for Japan.

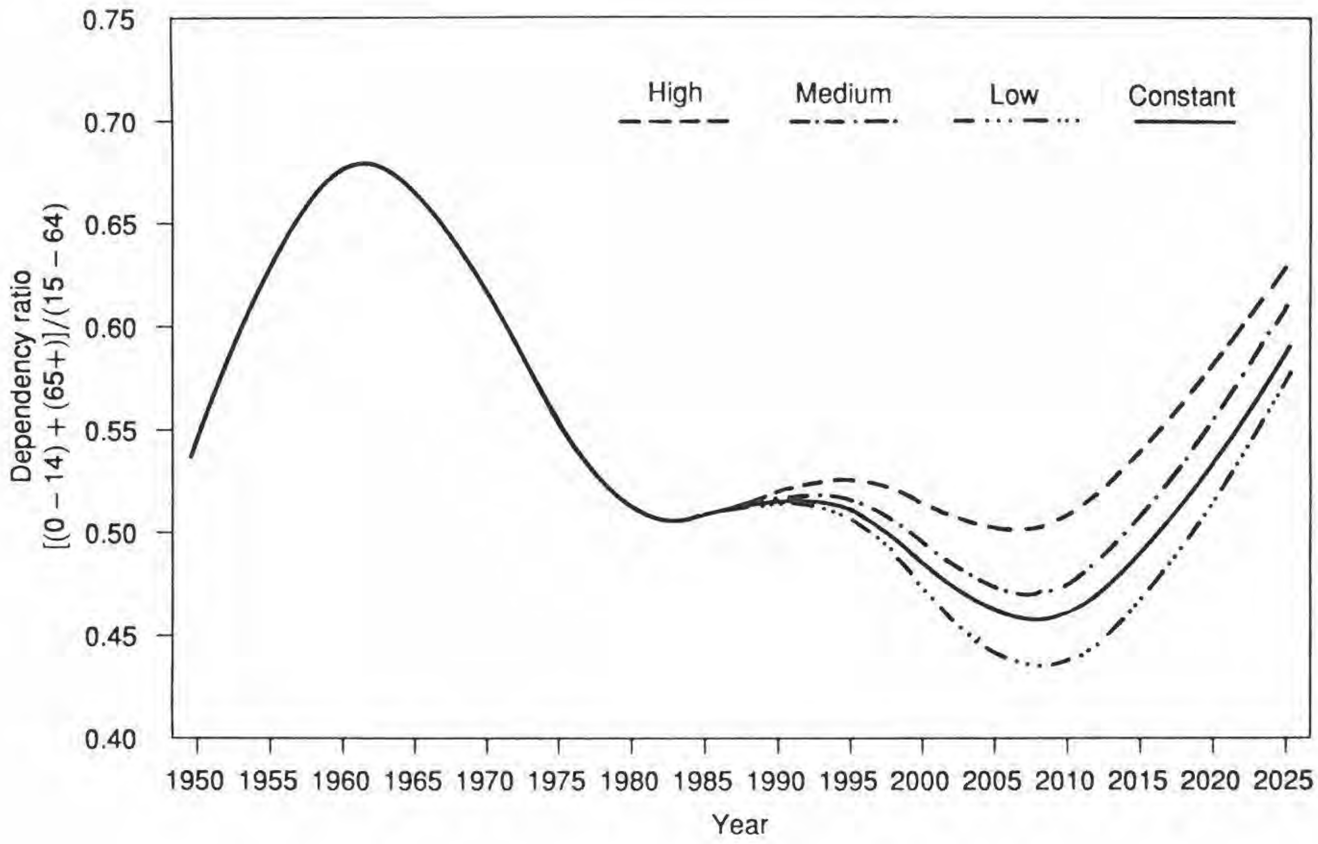

Figure 8.3. Dependency ratios for the United States.

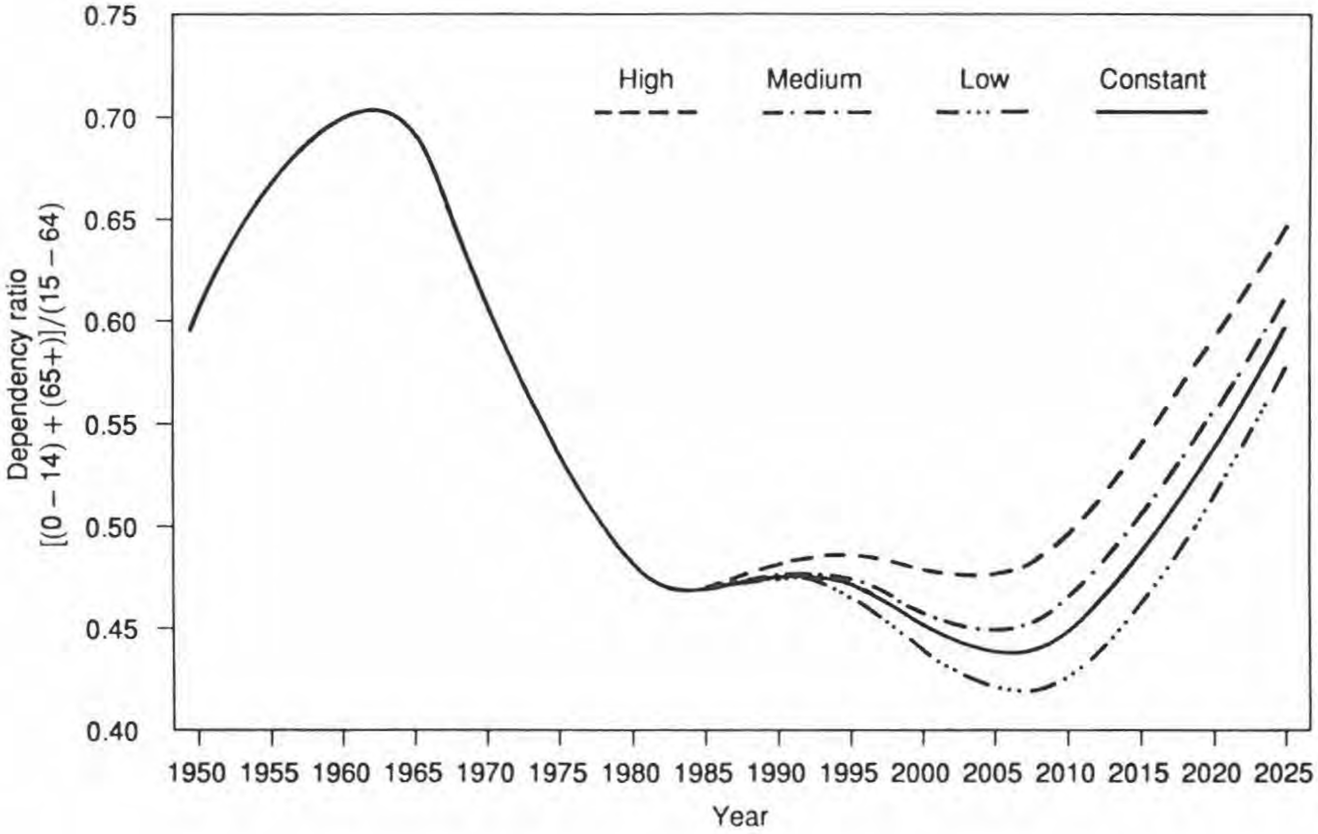

Figure 8.4. Dependency ratios for Canada.

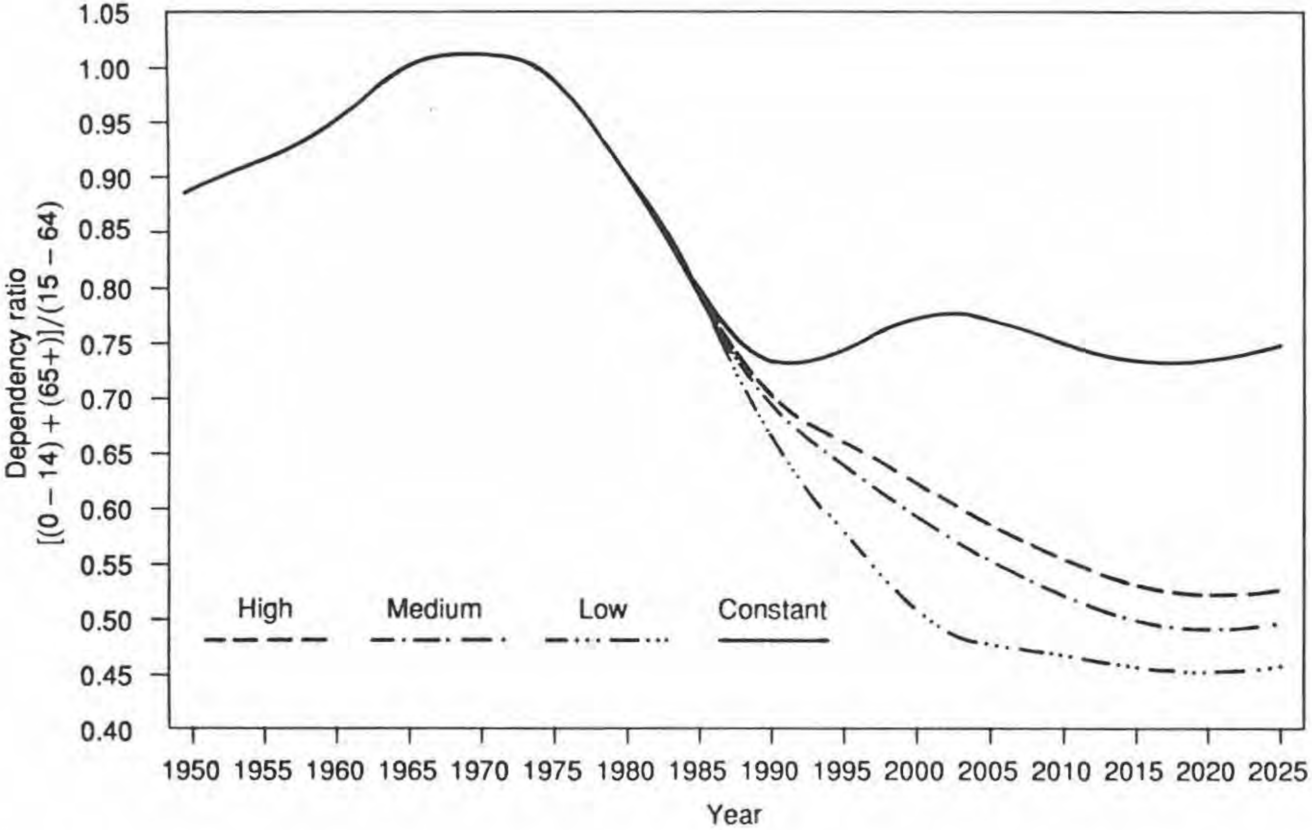

Figure 8.5. Dependency ratios for Mexico.

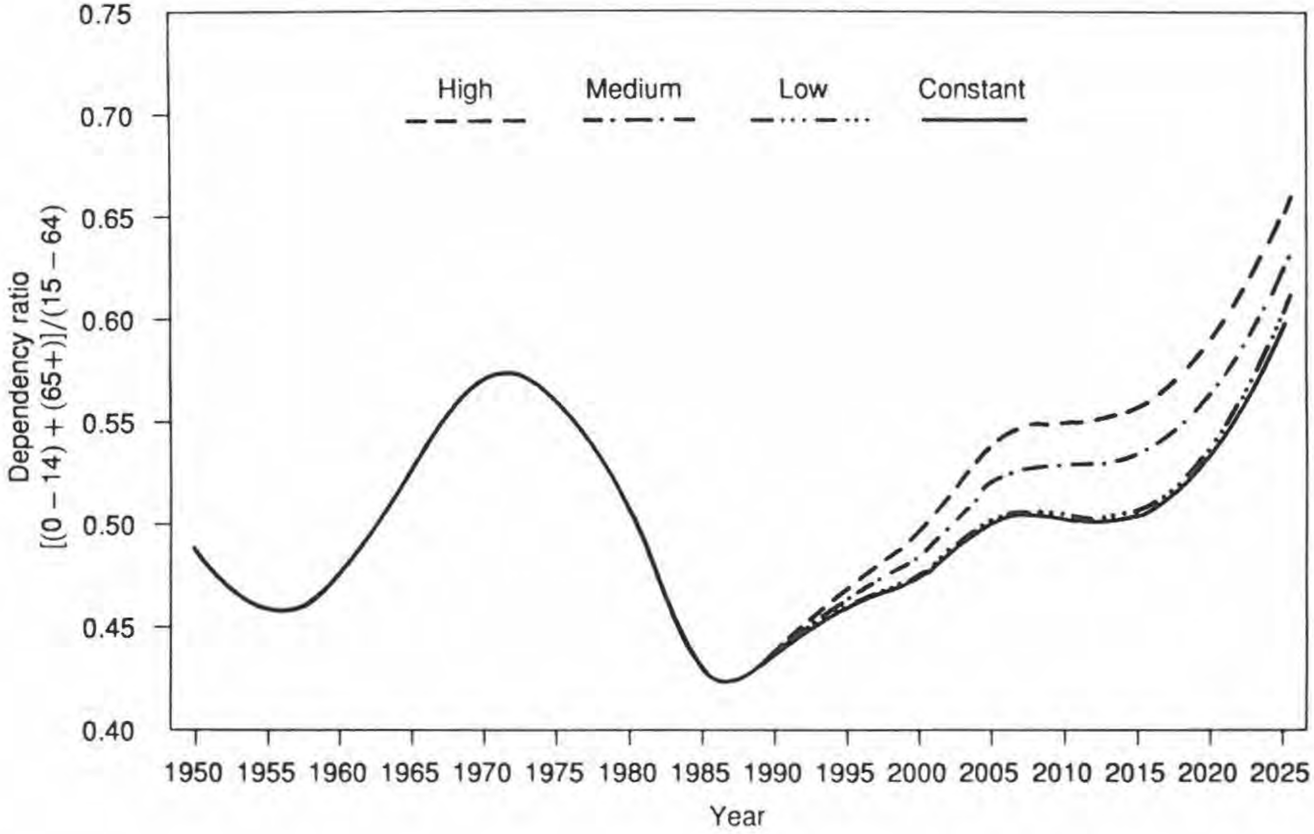

Figure 8.6. Dependency ratios for former West Germany.

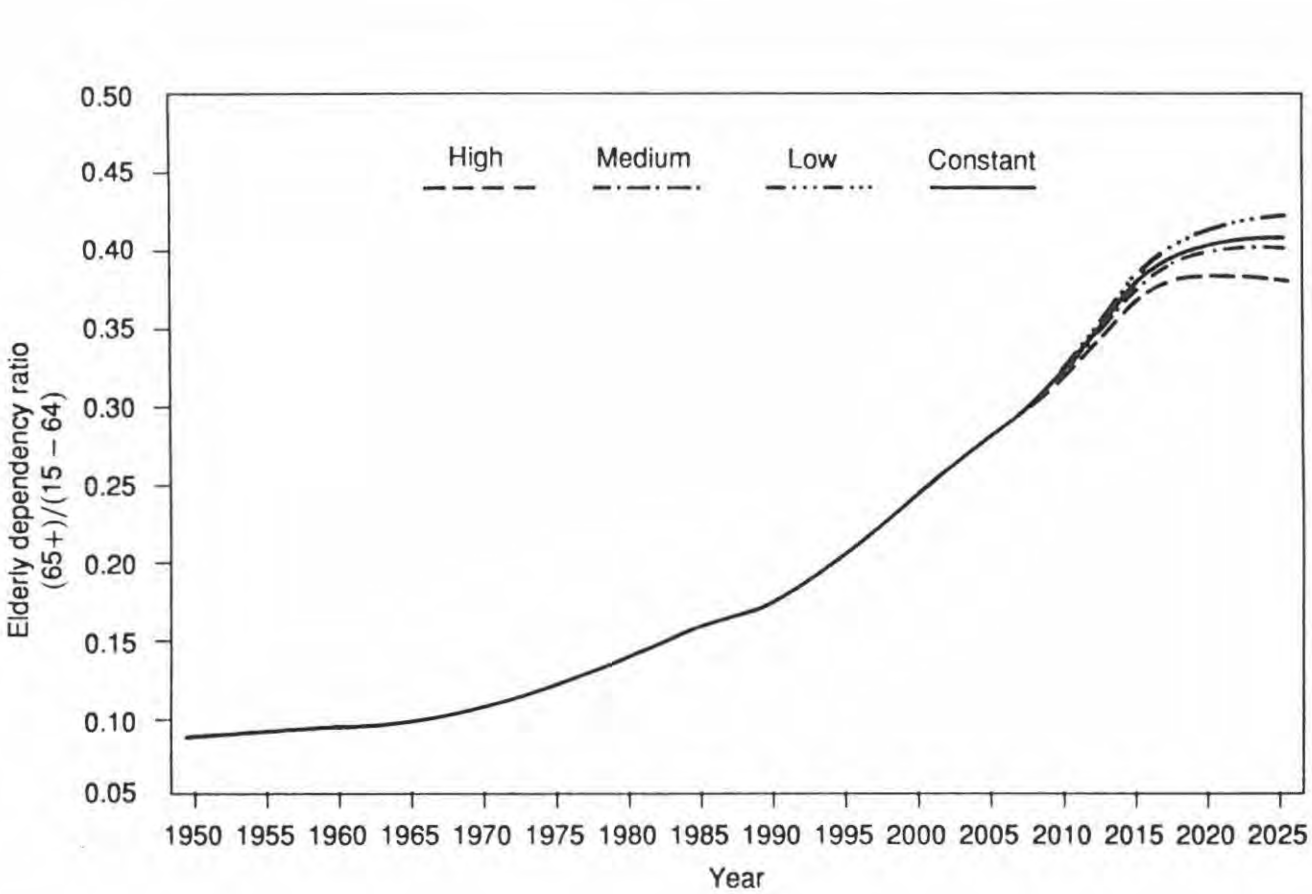

Figure 8.7. Elderly dependency ratios for Japan.

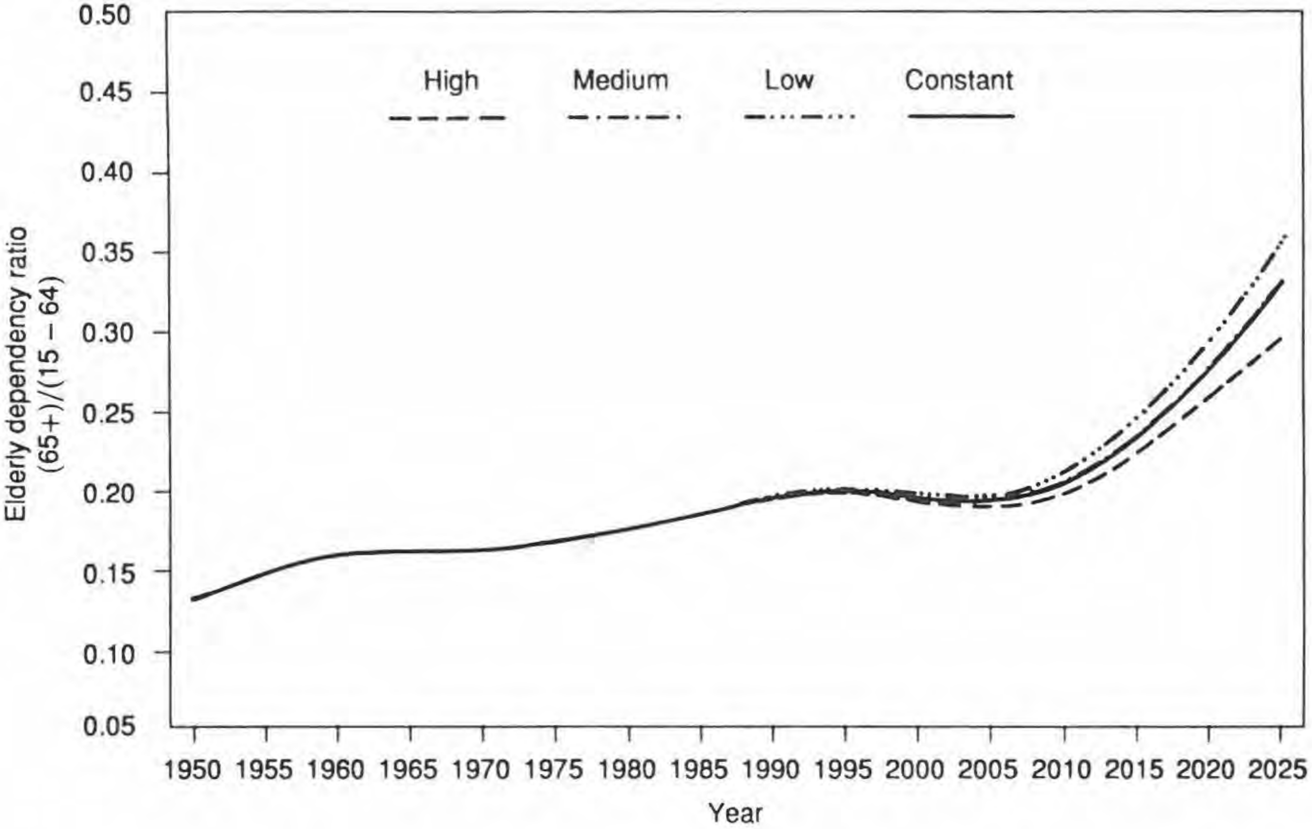

Figure 8.8. Elderly dependency ratios for the United States.

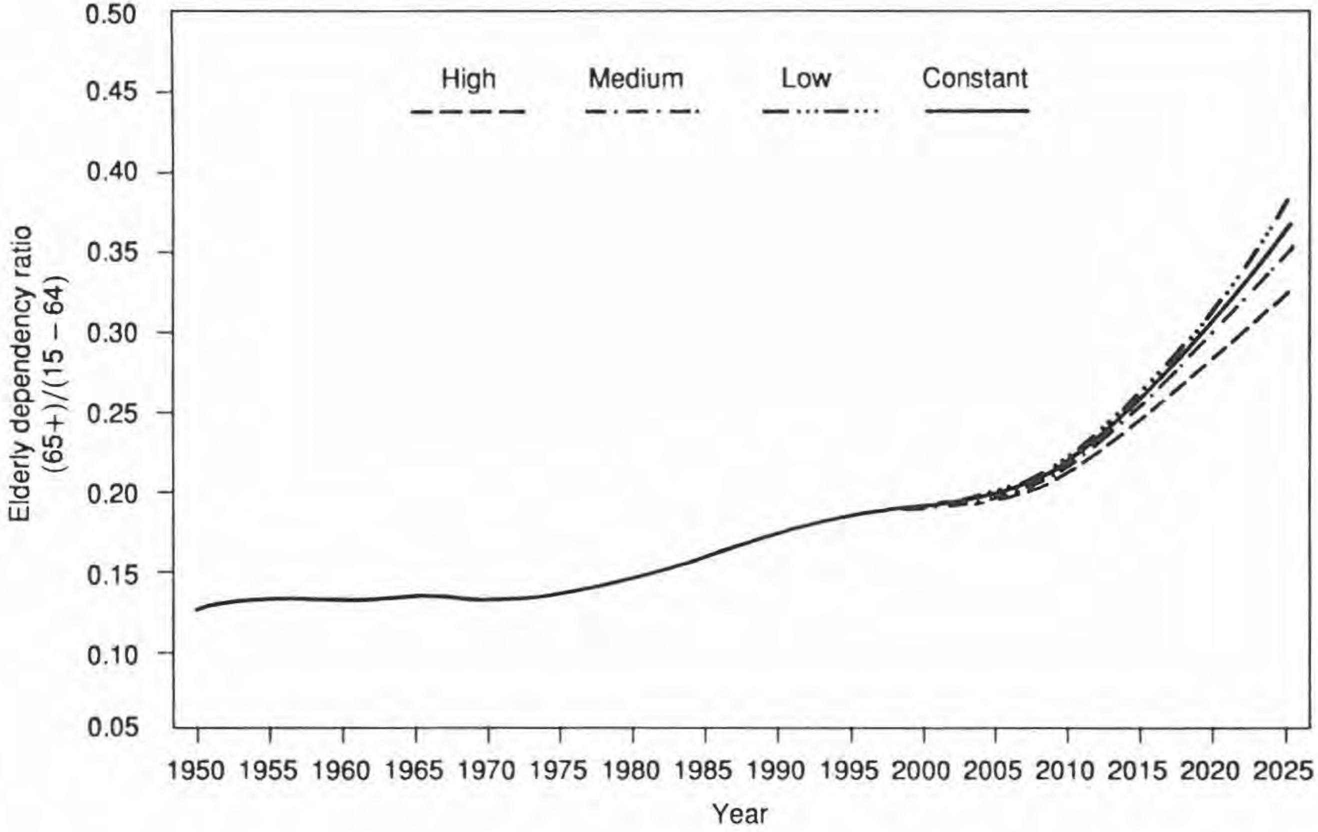

Figure 8.9. Elderly dependency ratios for Canada.

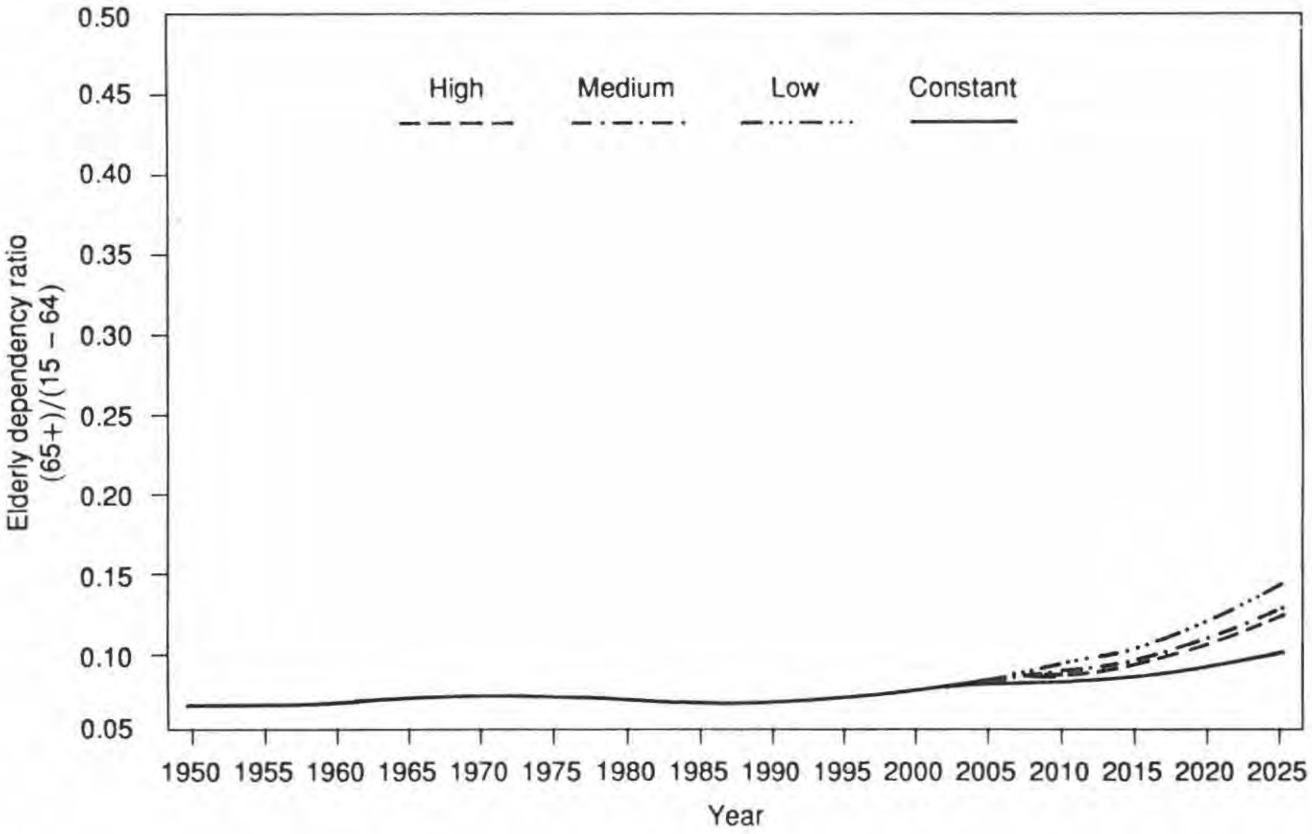

Figure 8.10. Elderly dependency ratios for Mexico.

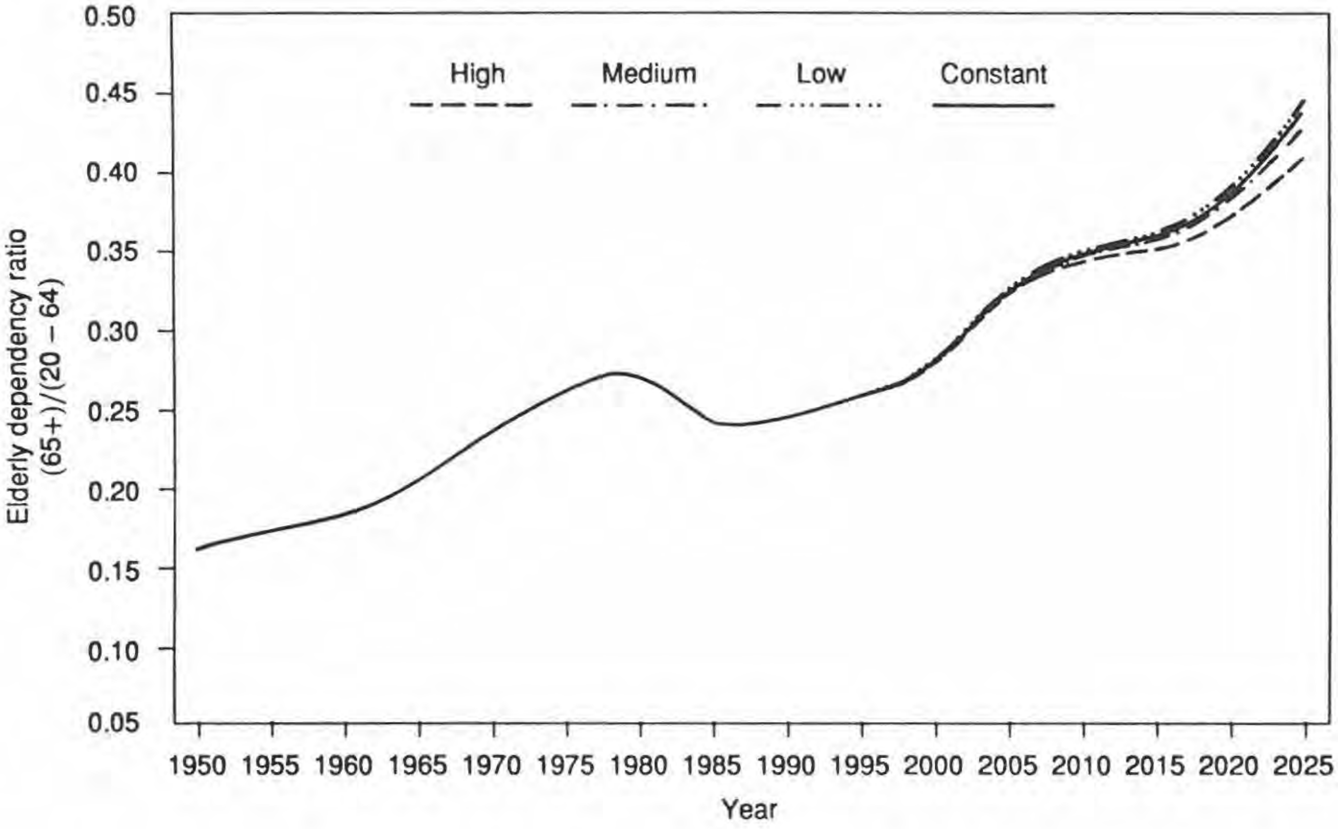

Figure 8.11. Elderly dependency ratios for former West Germany.

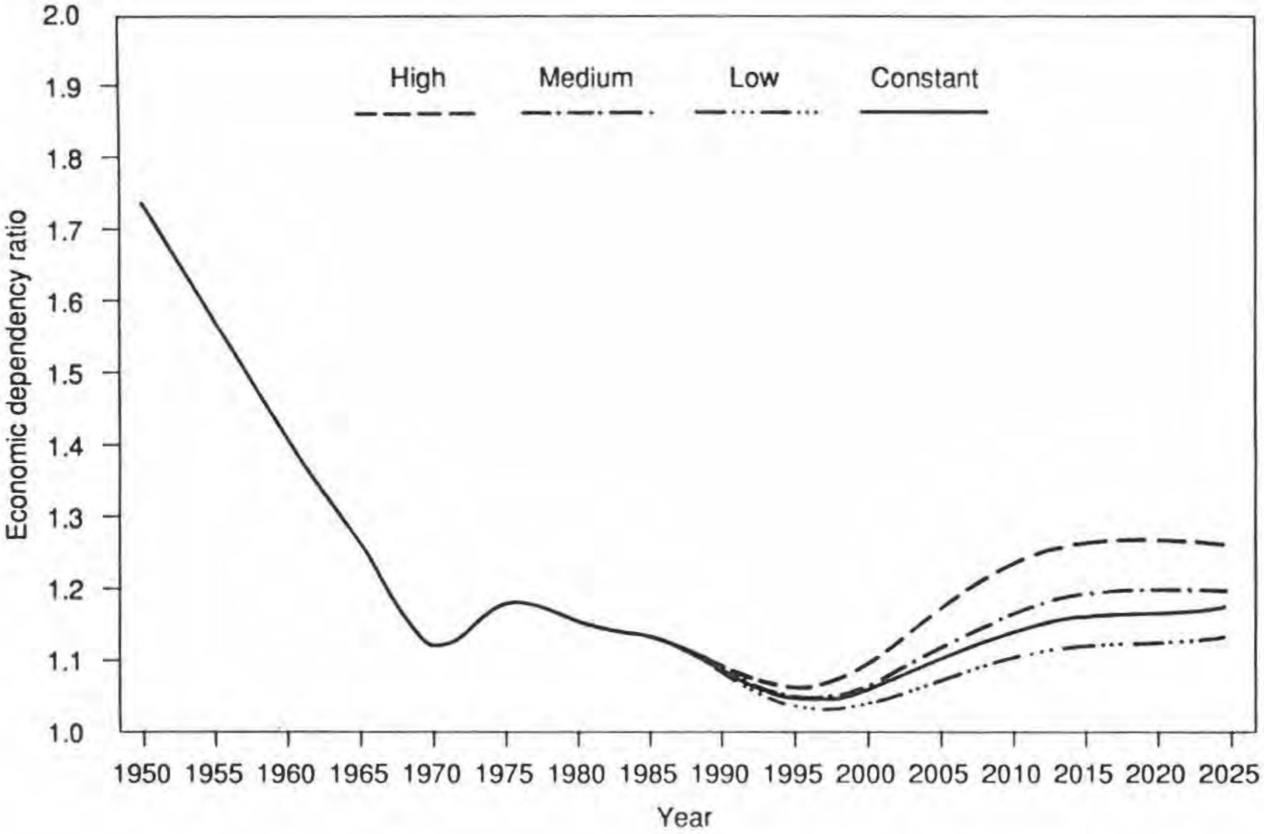

Figure 8.12. Economic dependency ratios for Japan.

Japan will have to face dependency ratios that are no larger than those experienced and dealt with successfully in the recent past.

There are interesting demographic consequences for Japan's economy during the next few decades. In order to investigate these consequences, econometric model building is becoming interdisciplinary, to the extent of including specific demographic variables. However, economic dependency may not be crucial. There is also a labor shortage, especially for certain skills and certain sectors. Some options for Japan are to:

1. Permit immigration (not relied upon previously).
2. Raise the retirement age.
3. Encourage more women to enter the paid labor force.
4. Try to raise productivity levels.

All four, and others too, will be used to some extent. In model building, option two can be readily incorporated by redefining the dependency measures. The graphs are considerably altered, for example, if retirement is put at age 70 instead of 65.

There are three main economic consequences of these demographic changes that have caused reformulations of econometric models in Japan. One effect of the aging process is to induce lower savings rates. These rates have played a key role in Japan's expansion since the mid-1950s. They provided abundant financial capital to support large-scale, fixed investment. Secondly, aging tends to lower productivity, a factor that has also been instrumental in Japan's growth. Finally, the aging population requires significant benefit payments from the social insurance system, which could be an economic burden for the future.

In an interesting econometric study supported by a Japanese insurance company, entitled *The Econometric Analysis of the Pension System: Its Effect on the Japanese Economy*, Drs. Yoshihisa Inada (Kobe-Gakuin University), Kazuo Ogawa (Kobe University) and Masayuki Tamaoka (Kobe University) explicitly introduced population by age and sex, and labor force participation by age and sex, in their macroeconometric model of Japan.[8] Their objective was to simulate different scenarios for policy makers to study.

The dependency ratios are not used as such in their model, but the solution provides estimates of both the numerator and the denominator of equation (8.6), so the ratios can easily be estimated. Population is not made endogenous, but it could, in principle, be introduced in that way. However, the labor force figure is generated by explicit equations for age and sex.

The principal features of this interdisciplinary model are that savings rates are inversely dependent on social insurance benefits per legitimate (older) recipient and on the population frequency of older persons. Specific expenditures, such as for housing, depend positively on the relative frequency of the population in young to medium working age groups. Social insurance benefits and medical costs depend positively on the population frequency of the elderly. As for productivity effects, the labor input variables in the technical production function are weighted by relative quality (wage) in the different age groups of labor input.

The Japanese model, with many demographic measures, is an unusual case, but is indicative of what is now being done. Several of the exogenous demographic variables will eventually be made endogenous, but, at least, their detailed impact on the economy is carefully being taken into account. This is definitely a step forward and deals with a very significant problem which has demographic roots.

The authors experimented with raising (by 10%) the pension level. This resulted in a decrease in private savings by as much as 2.5–9.1% along the 8-year time path of projection. This leads to investment and aggregate output declines. Any number of different scenarios may be implemented from their model.

An entirely different kind of model is being prepared and discussed in order to deal with the changing political institutions in Moscow. An econometric model of the former Soviet Union was built and maintained for a number of years, starting in 1973, at the University of Pennsylvania.[9] This model performed workhorse service for many research organizations and forecasters until the downfall of the USSR, which was both a political and an economic event. The model did not foresee the downfall, but it did monitor the Soviet pattern of economic development as long as the system held together. Now that an entirely new system and new geographical entity is in place it is useful to consider a replacement model.

This involves both political science (or political environment) and economics.

For many years the American Economic Association and the Economic Sections of the Academy of Science of the USSR conducted exchange programs of mutual interest, alternating between meetings in the USA and in the USSR. After the political changes in the USSR (glasnost), the exchange program shifted its focus of attention – to the economic problems of the USSR. Between November 27 and 29, 1990, a meeting was held in the United States, the subject of which was one that was favored by the Soviet side, namely, a discussion of the meaning and working of a price system. For this meeting, Herbert Scarf of Yale University prepared a special paper entitled "*Economic Equilibrium and Soviet Economic Reform.*"

The Scarf paper described an algorithm for computing general equilibrium prices, and the ensuing discussion prompted our Soviet colleagues into inquiring how a set of "shadow prices", generated by Scarf's algorithm, might serve the Soviet economy in realizing "perestroika".

Accordingly, a second meeting was held in Moscow in March 1992 on the problem of the valuation of wealth of the USSR, focused more narrowly on Russia with some attention, also, on other states in the former USSR, as a consequence of the political changes that had occurred since our previous meeting.

Valery Makarov, inspired by the discussion on Herbert Scarf's paper, prepared a Computable General Equilibrium Model (CGE) of Russia, and also targeted it toward the former republics of the USSR, as an example of the form of model-building that would conform to the new political realities. The Makarov model was the first attempt by the Russians (Soviets) to try to carry out careful macroeconometric modeling of their own country for contemporary decision making. Actually, the goal of Makarov's effort is to develop a sub-LINK system for the USSR, through the medium of linked republic models. This is an interdisciplinary model-building exercise in the sense that it tries to conform to the new political environment.

A conventional macroeconometric approach could not be used because a good data base is not readily available for the new political entities. Economic theory and judgment, which are used to a great extent in CGE models to supplement econometric inference from observed samples, were used by Makarov to prepare a model of Russia and to initiate one for Armenia. From the solution of such a model, "shadow prices" (in the manner of Scarf) could be used as initial values, for example, in valuing assets for privatization.

There are many other possibilities for introducing formal political considerations into macroeconometric models, but the CGE approach in terms of the present political realities in the former Soviet Union may be the choice required now.

Notes

[1] There are many ways to introduce formal linkages at the short-term level, but a proposed approach is presented in the following reference: Klein, L.R. and Sojo, E., 1989, Combinations of High and Low Frequency Data in Macroeconometric Models, in L.R. Klein and J. Marquez, eds., *Economics in Theory and Practice: An Eclectic Approach*, pp. 3–16, Kluwer Academic Publishers, Dordrecht, The Netherlands.

[2] Valavanis-Vail, S., 1955, An Econometric Model of Growth, USA 1869–1953, *American Economic Review* **45**(May 1955):208–221.

[3] Easterlin, R.A., 1961, The American Baby Boom in Historical Perspective, *American Economic Review* **51**(December 1961):869–911.

[4] See Metcalf, C., 1972, *An Econometric Model of the Income Distribution*, Markam, Chicago, IL, USA; Fair, R. and Dominguez, K.M., 1991, Effects of Changing Age Distribution on Macroeconomic Equations, *American Economic Review* **81**(December 1991):1276–1294; and Inada, Y., Ogawa, K., and Tamaoka, M., *The Econometric Analysis of the Pension System – Its Effect on the Japanese Economy*, 25 November 1991, Kobe-Gakuin University, Unpublished.

[5] Klein, L.R. and Kosaka, H., 1987, The Arms Race and the Economy, in B. Korte, ed., *Vorträge des Festkolloquiums aus Anlaß des 70. Geburtstages von Wilhelm Krelle*, pp. 9–56, Grundmann, Bonn, Germany.

[6] Kaufmann, R., Li-H., and Pauly, P., 1991, *Global Macroeconomic Effects of Carbon Taxes: A Feasibility Study*, prepared for the EPA (Contract 68-W8-0113), Work Assignment 58, June 1991, Washington, DC, USA.

[7] See the illuminating discussion in Saito, M., 1992, The Development of the Nationwide Econometric Model, *The Economic Studies Quarterly* **43**(March 1992):1–18.

[8] Inada, Y., Ogawa, K., and Tamaoka, M., 1991, *The Econometric Analysis of the Pension System - Its Effect on the Japanese Economy*, 25 November 1991, Kobe-Gakuin University, Unpublished.

[9] Green, D. and Higgins, C., 1977, *SOVMOD, I: A Macroeconometric Model of the Soviet Union*, Crane, Russak, New York, NY, USA.

PART V

How to Disseminate the Knowledge that Will Create a Constituency for Sound Policies

CHAPTER 9

International Environmental Governance: Building Institutions in an Anarchical Society

Oran R. Young

We have entered a period of profound changes in our understanding of governance in international society. Not only does this intellectual sea change offer an exciting new research agenda for students of international affairs, but it also opens up an unparalleled opportunity to bridge the gap that has long separated the main streams of research in the fields of international relations and political science.[1] In this chapter, I explore the implications of this development, with particular reference to international environmental affairs, and propose a plan of action to bring our new understanding of international governance to bear on environmental issues of current interest to policy makers, such as climate change and the loss of biological diversity.[2] However, the underlying argument is generic: it should attract the attention of those whose substantive concerns center on matters of peace and security, economics, and human rights, as well as those endeavoring to deal with environmental matters.

Defining the Problem: Governance without Government

Throughout much of the 20th century, a broad spectrum of students of international affairs have joined forces in arguing that the politically decentralized or anarchical character of international society constitutes a profound defect to be remedied as quickly as possible through the initiation of processes intended to eventuate in the establishment of a world government.[3] Prescriptions for achieving this goal have varied widely, ranging from the contractarian ideas of those who have advocated the achievement of "world peace through world law", to the incrementalism of those who propose to rely on the processes of spillover articulated in functionalist or neo-functionalist thinking.[4] However, all concur in concluding that we cannot hope to secure peace or achieve order, much less promote justice or other valued ends, at the international level in the absence of some form of government. A natural outgrowth of this way of thinking is a marked tendency among students of international affairs to look to experience with domestic systems as a source of inspiration, while students of domestic politics have seldom thought to turn to the study of international society as a source of helpful ideas about governance.[5]

Changes affecting this line of thought, stimulated by a number of developments which have unfolded over the last decade, are now beginning to coalesce into an alternative picture of international governance. In part, this is a consequence of the growing realization that domestic political systems, much like markets, often fail in ways that can, and do, lead to inefficiencies and to unfortunate outcomes measured in terms of other values. Under the rubric of government failure, for example, analysts are now exploring an array of problems centering on institutional arthritis resulting from progressive bureaucratization, the capture of public agencies by special interest groups, the impact of repressive measures carried out in the name of the state, and, ultimately, the breakdown of order eventuating in civil strife.[6] Simply establishing a government, we have learned from painful experience, offers no assurance that the function of governance will be fulfilled effectively, efficiently, and equitably: it may impose terrible costs at both the individual and the societal levels.

Of equal importance is the emerging awareness that fulfilling the function of governance does not always require the creation of material entities or formal organizations of the sort we associate with the concept of government. At the most general level, governance is a matter of establishing social institutions (in the sense of rules of the game that give rise to and define social practices) capable of resolving conflicts, facilitating cooperation, and, more generally, alleviating collective-action problems in a world of interdependent actors.[7] Nothing in this way of framing the issue presupposes a need to create material entities or organizations (that is, governments) to administer the rules of the game that arise to handle the function of governance. Once we set aside our preoccupation with structures of government, in fact, it is readily apparent that governance is by no means lacking in international society, despite the conspicuous absence of a material entity possessing the authority and the power to handle the functions of governance for this society as a whole.[8]

The introduction of the idea of governance without government raises a host of new questions of interest to students of politics in general and to students of international relations more particularly.[9] Granted that governance systems unencumbered with public authorities sometimes suffice to circumvent or to solve specific collective-action problems (such as the tragedy of the commons), is there nonetheless a price to be paid for relying on governance systems of this sort when it comes to values like maximizing social welfare or ensuring robustness in the sense of a capacity to adapt to changing social or material circumstances?[10] Having articulated a clear distinction between governance systems in the sense of social institutions and governments in the sense of material entities or organizations, can we now begin to explore interactions and linkages between the two? Are there roles for organizations, for example, in establishing governance systems in a variety of issue areas?[11] Can organizations that are issue specific and more modest in scope than what we think of as governments play constructive roles in the administration or operation of governance systems? Do governance systems go through recognizable lifecycles which are marked, among other things, by a tendency to rely increasingly on organizations with the passage of time? Is it normal for the resultant organizations to build linkages among issue areas so that they eventually come to resemble our conventional idea of government? Are the prospects for governance without government tied to particular characteristics of the social setting so that arrangements that are successful in some settings (for example, small-scale, traditional societies) are not likely to prove viable in others (for example, international society)?[12]

Identifying Environmental Problem Sets

Given the recent preoccupation with global environmental issues (for instance, ozone depletion and climate change), it is important to preface an examination of environmental governance systems with a discussion of the range of environmental issues or problem sets now requiring attention at the international level. Many efforts to classify these issues are based on properties of the relevant physical or biological systems. Useful as the resultant classifications are for some purposes, there are good reasons to conclude that they are not well-suited to efforts to deepen our understanding of the theory and practice of international governance. Success in the formation and administration of environmental governance systems depends critically on the extent to which these arrangements are tailored to fit the juridical and political attributes (as well as the physical and biological properties) of the problems at hand. From this perspective, there is much to be said for distinguishing among international commons, shared resources, and transboundary externalities.

International commons are physical or biological systems that lie wholly or largely outside the jurisdiction of any of the individual members of international society, but that are of interest to a number of actors as valued resources. Commons of current interest include Antarctica, the oceans, deep seabed minerals, the electromagnetic spectrum, the geostationary orbit, the stratospheric ozone layer, the global climate system, and outer space.[13] As these examples suggest, international commons may be geographically limited, as in the cases of Antarctica and deep seabed minerals, global in scope, as in the case of the climate system, or even more comprehensive, as in the case of outer space. The category of international commons has expanded over time as a result of the introduction of new technologies allowing humans to gain access to previously inaccessible areas or to engage in previously infeasible activities: it has also shrunk as a consequence of efforts to extend the jurisdictional reach of the individual members of international society. The electromagnetic spectrum and the geostationary orbit, for instance, have come into focus as highly valued commons during this century, with the advent and diffusion of modern communications systems.[14] Marine areas adjacent to the coastlines of states, on the other hand, have lost many of the attributes of commons as a result of the extension of the jurisdiction of coastal states to offshore areas and, especially, the recent establishment of exclusive economic zones in broad coastal belts.

Three broad options are available to those endeavoring to devise governance systems for international commons: world government, extended national jurisdiction, and restricted common property. Those, like Garrett Hardin, who are preoccupied with the idea of the tragedy of the commons often prescribe mutual coercion mutually agreed upon as the best means of avoiding or coming to terms with the dangers they associate with human use of the commons.[15] At the international level, this would entail establishing a world government possessing the authority to make, and the power to ensure compliance with, rules relating to the use of commons areas. The idea of extending national jurisdictions, in contrast, flows from the premise that the tragedy of the commons is largely a consequence of inappropriate assignments of property rights, a problem that can be avoided by engineering a shift from common property to some alternative under which property rights (or at least grants of management authority) are accorded to individual members of the group.[16] In international society, this would require extending the jurisdiction or management authority of individual states to areas previously treated as commons.[17] A system of restricted common property is a form of governance that features the retention of the essential features of common property, coupled with the establishment of systems of rules to guide the behavior of individual members of the ownership group who wish to make use of the property.

Shared resources are physical or biological systems that extend into or across the jurisdictions of two or more members of international society. They may involve non-renewable resources (for example, pools of oil that underlie areas subject to the jurisdiction of adjacent or opposite states), renewable resources (for example, straddling stocks of fish or migratory stocks of wild animals), or complex ecosystems that transcend the boundaries of national jurisdictions (for example, regional seas or river basins). While it is natural to focus on shared resources of interest to adjacent or neighboring states, such resources may also link together states that are far removed from each other geographically, as in the case of migratory birds that traverse long distances and pass through numerous jurisdictions in the course of their annual cycles. Similarly, shared resources may impinge on the commons as well as the jurisdictional zones of more than two states, depending upon the attributes of the resources themselves and on the prevailing pattern of jurisdictional boundaries. Many marine mammals, for example, move through waters under the jurisdiction of several coastal states as well as waters that remain part of the high seas, even with the creation of exclusive economic zones. As this observation makes clear, moreover, the groupings of actors concerned with shared resources may expand or contract with shifts in jurisdictional boundaries in international society. While some fish stocks have dropped out of the category of shared resources as a result of the extension of national jurisdictions, for instance, others have moved into the category of straddling stocks as a consequence of the same jurisdictional changes.

The obvious solution to problems of shared resources is the establishment of joint management arrangements, either in the form of simple coordination regimes under which all participants agree to adhere to common rules or in the form of more complex regimes involving the creation of supra-national management authorities. There is a considerable body of experience with management regimes for renewable resources extending across jurisdictional boundaries (for example, the various regimes for migratory birds) and flow resources shared by two or more states (for example, the Great Lakes water quality regime in North America or the Rhine River regime in Europe).[18] Just as unitization has become a well-known and richly nuanced practice used in domestic society to manage the use of common pools of oil and other non-renewable resources extending across property boundaries, there is growing interest in creating joint development zones to handle analogous situations at the international level.[19] Yet this does not mean that the management of shared resources is a simple matter in international society. As experience with a number of river basins makes clear, there are often sharp conflicts of interest among the relevant states which make it difficult to devise any regime that seems adequate to solve the underlying problem, much less to produce outcomes that all participants regard as equitable.[20] In cases where recent shifts in jurisdictional arrangements have given rise to shared resource problems, there are also legitimate questions concerning the extent to which other states can make use of the principle of the common heritage of mankind as a basis for claiming some residual right to share in any proceeds accruing from the exploitation of the resources at stake.

Transboundary externalities arise when activities that occur wholly within the jurisdiction of individual states nevertheless produce results that affect the welfare of those residing in other jurisdictions. Sometimes the externalities in question center on intangible effects arising from moral interdependencies. The destruction of world heritage sites such as the temples at Angkor or the city of Dubrovnik, for example, detracts from the welfare of people everywhere, even if the benefits they derive from the existence of the sites are largely vicarious in nature.[21] Similarly, people everywhere now express genuine concern about the consequences of tragic environmental accidents (for example, Chernobyl or Bhopal), quite apart from any transboundary consequences of such incidents that are material in nature. In other cases, the externalities in question involve material interdependencies that affect the welfare of those located elsewhere in more tangible terms. A striking case that has now become a matter of widespread concern involves the stake of the rest of the world (measured in terms of values like the potential for the development of new drugs) in the loss of biological diversity caused by the destruction of moist tropical forests in Brazil and a small number of other countries. As economists are fond of pointing out, externalities may have positive as well as negative effects on the welfare of others: careful observers will no doubt be able to point to cases of positive externalities occurring at the level of international society. When it comes to problems of international environmental governance, however, it is apparent that the focus of attention is increasingly on the dangers of negative externalities.

Dealing with transboundary externalities in international society raises two issues of fundamental importance to those who analyze governance systems. Do the members of international society, acting as a group, have the authority to intervene in the domestic affairs of individual states, regardless of the wishes of the governments of those states, when events occurring within their jurisdictions pose severe threats to the welfare of others or to international society as a whole?[22] While we are often prepared to accept such interventions when the relevant activities pose a threat to international peace and security, an affirmative answer to this question in the case of environmental threats raises profound concerns in the minds of those committed to traditional conceptions of state sovereignty.[23] Nevertheless, the threats to human welfare now arising in conjunction with environmental issues – from the geographically focused impact of the Bhopal disaster to the worldwide impacts of climate change – are raising serious concerns about sovereignty that are destined to become more insistent with the passage of time.

There are also important questions regarding liability of states for the impacts on outsiders of activities taking place within their jurisdictions. Basing their thinking on general precepts (for instance, the "polluter pays" principle), some will undoubtedly argue that there is a need for the development of a more effective code of environmental liability rules in international society. But this approach cannot yield solutions for some of the most important problems arising in this area today. As many of those now struggling to deal with the environmental problems of the developing countries and the former socialist states are discovering, the most effective way to enhance environmental protection for one's own citizens or ecosystems often requires joining forces with polluters to provide them with the financial resources and the technological capabilities needed to alter their polluting practices.

Beyond this, it is predictable that governance systems created to deal with environmental problems will interact and sometimes conflict with similar systems set up to deal with a variety of other issues in international society. Perhaps the most striking and potentially controversial issues of this type that are rising to the top of the international agenda at this time involve, first, links between actions to protect the environment and efforts to promote economic development in the countries of the Third World, or, in other words, problems of sustainable development, and, second, connections between initiatives aimed at protecting or enhancing environmental quality and efforts to promote the growth of international trade.[24]

Consider the following cases. Does the protection of the stratospheric ozone layer or the global climate system require developing countries to forego the use of products or resources (for instance, fossil fuels) that have played key roles in the development of the advanced, industrial societies? Does the maintenance of biological diversity compel states like Brazil, Indonesia, and Malaysia to eschew strategies that may seem attractive to advocates of rapid economic growth? Similarly, does participation in a free trade regime (for example, the proposed North American Free Trade Area) require member states to take steps to homogenize their environmental standards at the same time? Or are individual members at liberty to persuade industries to locate within their jurisdictions with promises of less stringent environmental rules as well as cheaper labor? Are states free to impose restrictions on imports from other countries whose production involves practices they consider unacceptable on environmental grounds (for example, catching tuna in nets that also kill dolphins)? Or do such actions amount to restraints on trade that are impermissible under the terms of the governance system articulated in the General Agreement of Tariffs and Trade (GATT)?

In decentralized political systems, where governance without government is the order of the day, difficulties involving linkages of this sort are unavoidable. What is more, the higher the level of interdependence in the system, the more troublesome such issues are likely to become. No doubt, this fact constitutes an important part of the rationale articulated in many social settings for the establishment of governments, over and above the creation of governance systems. However, even in this connection, caveats are in order. As innumerable painful experiences with intergovernmental relations and interagency coordination within governments attest, the creation of a government offers no assurance that these linkage problems will be resolved successfully. Nor can we simply assume that such problems will prove intractable when governance systems are not accompanied by the formal organizations of government. Current efforts to come to terms with the linkages between environment and trade are particularly intriguing in this regard. While this set of problems has recently become a focus of considerable controversy between environmentalists and advocates of free trade, it would certainly be premature to conclude that it will prove impossible to negotiate acceptable accommodations among the governance systems in question without establishing some form of government to handle the issues at stake.

Analyzing International Governance Systems

What do we know, and what do we need to know, about past, present, and future international governance systems in order to deal effectively with contemporary environmental issues? What are the prospects of applying our general knowledge of governance systems to environmental problems in a manner that will prove useful to practitioners responsible for establishing such systems or operating them on a daily basis? The following discussion makes use of distinctions that are analytic in nature in the sense that it is impossible to separate the phenomena under consideration in any simple or clear-cut fashion. For purposes of analysis, however, it is illuminating to divide the research agenda into issues involving: institutional bargaining; the administration of governance systems; the effectiveness of institutional arrangements; and robustness and change.

The key provisions of governance systems, or, in other words, the rules of the game that serve to define social practices, are ordinarily articulated explicitly in constitutional contracts that are often, but not always, codified in legally binding instruments, like conventions or treaties.[25] Efforts to (re)form governance systems involve processes of ***institutional bargaining*** in which the participants seek to reach agreement on the terms of these constitutional contracts.[26] Unlike legislative bargaining, which typically centers on the building of winning coalitions to meet the requirements of a majoritarian rule, institutional bargaining in international society normally operates under a consensus rule that gives the participants an incentive to put together packages of provisions that will prove attractive to as many interests as possible. What saves the resultant bargaining from being doomed to certain failure or the negotiation of toothless agreements is the absence of perfect information and the expectation that governance systems, once formed, will remain in place over indefinite periods of time. These features of institutional bargaining introduce an element of "good" uncertainty in the sense that they give the participants incentives to engage in integrative rather than distributive bargaining and to deal with the resultant veil of uncertainty by settling on provisions that seem equitable to all.[27]

Why do those engaged in institutional bargaining succeed in establishing governance systems to cope with some environmental problems but fail to do so in connection with other, seemingly similar, problems? Questions of this sort have given rise to a substantial body of theoretical ideas concerning the formation of international governance systems.[28] For the most part, these ideas accentuate single factors, like material conditions (for example, hegemonic stability theory), institutional arrangements (for example, many game-theoretic analyses), or ideas (for example, arguments relating to epistemic communities). But recent work suggests that single-factor accounts are severely limited in efforts to account for the formation of international governance systems. The challenge before us, then, is to devise a multi-variate model of the (re)formation of international institutions.[29] In the minimum case, such a model should make it possible to understand substitution effects in the sense of alternative pathways to the creation of governance systems, and interaction effects in the sense of multiple forces at work in the development of individual governance systems.

The preceding discussion has made use of a clear-cut distinction between *institutions*, treated as the rules of the game that define the character of social practices, and *organizations*, understood to be material entities possessing offices, personnel, equipment, budgets, legal personality, and so forth.[30] However, it does not license the conclusion that we should turn the traditional study of international governance on its head by devoting all our attention to institutions (that is, governance systems) and ignoring organizations (that is, intergovernmental organizations) altogether. There is an important sense, on this account, in which governance systems take precedence over organizations. Since it is possible for governance systems to arise and operate in the absence of organizations, it falls to advocates of international organizations to demonstrate the importance of these organizations to the achievement of international governance. When organizations are needed, moreover, it is important to tailor them to the requirements of specific governance systems, rather than changing institutions to achieve compatibility with pre-existing or preconceived organizations. Even so, one of the principal virtues of drawing a distinction between institutions and organizations is that it opens up a major research agenda concerning interactions between the two. Thus, organizations not only play roles of some importance in the establishment of many governance systems in international society, but they also assume key roles in the day-to-day management or administration of many governance systems.[31]

Why are some international governance systems more successful than others at solving the problems that motivate their establishment? More modestly, why are some systems better than others at inducing their members (and other relevant actors) to act in conformity with the rules of the game? To ask these questions is to launch an enquiry into the *effectiveness of institutional arrangements* in international society.[32] A governance system that channels behavior in such a way as to eliminate or substantially to ameliorate the problem that led to its creation is an effective system. A governance system that has little behavioral impact, in contrast, is an ineffective system. As these observations imply, the concept of effectiveness as applied to international governance systems defines a continuous variable. Governance systems can and do range from ineffectual arrangements, which have few behavioral consequences, to highly effective arrangements, which produce quick and clear-cut solutions to the problems at stake. Note also the distinction between effectiveness and the performance of governance systems measured in terms of normative criteria. A governance system may affect behavior dramatically, for example, without achieving great success in terms of criteria like efficiency, equity, or sustainability.

While students of domestic politics generally take it for granted that institutions matter and set about analyzing the nature of their impact, there is a strong current of thought among students of international affairs that dismisses institutions as epiphenomena. In this "realist" view, governance systems are surface phenomena, or epiphenomena, that reflect the underlying configuration of power in international society. Such arrangements come and go with shifts in the political fortunes of powerful actors and without affecting outcomes much in their own right.[33] Yet others see institutions, along with material conditions and ideas, as one of the major clusters of factors that determine the course of international affairs. And it is surely inappropriate to dismiss international governance systems as ineffectual just because they are not linked together to form some sort of world government. The analytic challenge in this realm is to devise procedures to allow us to focus on the behavioral effects of international institutions, while holding other factors constant or controlling for their effects. Though this challenge is a tough one, research is now underway that should begin to illuminate this issue during the near future.[34]

Nothing is static in the world of international governance systems. Existing arrangements evolve under pressure from a variety of forces. New institutions emerge, while old arrangements pass from the scene. This suggests a number of questions concerning the *dynamics of international governance.* Are some governance systems more robust than others in the sense that they are better at adapting to changing problems and shifting societal conditions? If so, what are the determinants of robustness? Do some governance systems exhibit a capacity to control the social environment in which they operate as a means of achieving robustness? Are there feedback loops that set up interactive relationships between governance systems and the social environments in which they operate? Does it make sense to think of such systems as passing through institutional lifecycles in the sense that they initially gain in robustness, achieve a measure of stability, and eventually run into problems that lead to their decline and even demise?

As in the case of effectiveness, our current understanding of the dynamics of international governance systems is sharply limited.[35] To start, however, it makes sense to draw a distinction between internal factors and external factors in thinking about institutional dynamics. A study of internal factors leads us to focus on governance systems themselves in the interests of determining whether they encompass powerful equilibrating mechanisms, as many proponents believe is the case with competitive markets, or, alternatively, harbor the seeds of their own destruction, as Marxists and other radical thinkers have always maintained is the case with capitalist systems. This perspective also leads us to ask whether the breakdown of governance systems is apt to be gradual in nature or to involve sudden and sharp non-linearities of the sort envisioned in chaos or catastrophe theory. External factors, in contrast, may range from changes in material conditions (for example, the introduction of new technologies or a reconfiguration of power in international society) to shifts in prevailing systems of thought (for example, the rise of the conservation movement in the 20th century).[36] Of course, these internal and external forces are not mutually exclusive. On the contrary, any serious study of robustness and change in international environmental governance systems will need to focus on links and interaction effects among these forces to account for the variety of patterns that are empirically observable.

Building Intellectual Capital

The preceding discussion makes it clear that the creation of effective environmental governance systems in international society poses a profound challenge, in intellectual terms as much as in policy terms. While knowledge of the relevant physical and biological systems is expanding rapidly, our current understanding of international governance systems is inadequate to meet the rising demand for governance associated with the array of environmental problems that threaten to engulf us. We are increasingly in danger of being overtaken by environmental crises that unfold so rapidly that they leave little time for reflection, much less adaptation, once they are upon us. But our knowledge of international environmental governance still consists largely of *ad hoc* observations drawn from unsystematic readings of individual cases.

Meeting the challenge before us will require new ways of thinking as well as new capacities to act. Specifically, we must:

- Move beyond anecdotal accounts to the development of broader, well-tested propositions and principles relating to the (re)formation and operation of international environmental governance systems.
- Initiate a mutually rewarding dialogue between those concerned with basic and applied issues pertaining to environmental governance.
- Transcend the boundaries of existing disciplines and modes of thought in the search for new intellectual capital.
- Bridge the gap among the cultures of science, policy making, and public administration with regard to matters of environmental governance.
- Enhance our ability to learn our way out of environmental crises by fostering social change rather than relying solely on technical solutions.

To develop the intellectual capital needed to meet this challenge creatively, there is a need to establish a trans-national network to foster communication among those working on issues of international environmental governance.[37] Such a network would benefit from having an administrative node located in a non-profit setting (probably at a major university), but it should also encompass a sizable collection of participants working in different parts of the world and drawing on a variety of intellectual traditions. In essence, the network would endeavor to serve as a source of well-founded ideas available to all those concerned with environmental governance at the international level, becoming, in the process, a powerful instrument for bringing new insights to bear on current environmental concerns, monitoring the performance of existing environmental governance systems, and adding to our overall understanding of international governance.[38]

More specifically, an international environmental governance network, operating on the basis of an agreed division of labor among its constituent members, should play five distinct, though obviously related, roles.

- *Information and data.* The network should become the principal repository of information and data pertaining to international environmental governance systems operative in the past or in operation at the present time. These materials should encompass information concerning environmental problem sets (including players, interests, issues, and the state of knowledge about them), as well as information about the operation and evolution of governance systems designed to solve these problems. The materials would include information on the efforts of various players to alter existing governance systems and on the efforts of those responsible for administering governance systems to induce members to comply with their rules. They should be updated on a continuous basis and made available to practitioners and scholars alike at a nominal cost, both online and through more conventional procedures.
- *Research and analysis.* The network should sponsor both basic and applied research on international environmental governance systems. Such research should encompass targeted analyses of interest to those responsible for designing and administering specific environmental regimes, as well as investigator-initiated research dealing with generic and theoretically significant issues in this field of study. The network's administrative node should provide ongoing support for the research of longstanding network members: it should also make provisions for accommodating research associates who would spend varying lengths of time working on specific projects. A high priority should be accorded to initiatives designed to maximize communication between scholars seeking insights of a generic nature concerning governance systems and practitioners possessing in-depth knowledge of specific cases. A particularly important goal in

this realm should be the development of a set of institutional indicators that could be used to monitor the performance of individual governance systems on a continuous basis.[39]

- *Advisory services.* The members of the network should be able to draw on their collective resources to provide advisory services to those responsible for the establishment and administration of specific international environmental governance systems. In some cases, this may be a simple matter of making factual information accessible in an efficient manner. In other cases, advisory services will require sustained analysis to project the probable consequences of institutional options under consideration or to diagnose problems arising in connection with governance systems currently in place. The members of the network should adopt a policy of offering advisory services to all those prepared to pay for them, including national governments, intergovernmental organizations, and non-governmental organizations. Some provision should be made to allow parties possessing legitimate interests in international environmental issues, but lacking resources, to obtain access to these advisory services.
- *Training.* The network should offer training programs to those charged with both the establishment and the administration of international environmental governance systems. The network should be prepared to develop training courses of its own design and to make them available on a first-come, first-served basis. Additionally, it should work with interested parties to tailor training courses to the needs of specific groups. The resultant programs, which would normally be intensive sessions lasting one to two weeks, should be portable in the sense that they could be put on at many locations with a minimum of administrative effort.
- *Dissemination.* The network should seek to disseminate information and ideas relating to international environmental governance systems on a regular basis. This task might well encompass the publication of information bulletins concerning the activities and offerings of network members, research papers and conference reports, and monographs setting forth the

results of major scholarly studies. Every effort should be made to take advantage of modern communications technologies, like computer conferences available on electronic networks. This would make it possible to forge strong bonds among the network's widely dispersed members and to contribute to the growth of an international environmental governance community. It would also allow practitioners to access the ideas produced by network members quickly and inexpensively.

In Conclusion

We are in the midst of a sea change in our thinking about governance in international society. The essence of this change is a shift from a focus on organizations in the material sense, which emphasizes the role of government in domestic societies and the deficiencies of international society in this regard, to a concern for governance systems, which directs attention to social institutions and the prospects of achieving governance without government. Nowhere is the potential of this shift to illuminate important issues greater than in the realm of international environmental affairs. Despite the energizing effect of this realization, however, there are no grounds for complacency about its value as a source of solutions to the environmental problems confronting policy makers on a day-to-day basis. We are just beginning to understand the factors controlling the creation of environmental governance systems. We have barely scratched the surface in thinking about what makes some international institutions more effective than others. Above all, our capacity to design successful governance systems to deal with the specific environmental problems now confronting us at the international level is severely limited. These limitations do not constitute grounds for pessimism; far from it. But they do present a challenge to our intellectual ingenuity. As part of a strategy for meeting this challenge, it would help to create an international environmental governance network, a mechanism that could serve as a flexible instrument for drawing together practitioners and scholars to extract lessons from prior experience with governance systems and to apply these lessons creatively to the environmental problems now coming into focus in international society.

Notes

[1] For an account that reflects important new thinking about governance among political scientists and sociologists see Campbell, J.L., Rogers Hollingsworth, J., and Lindberg, L.N., eds., 1991, *Governance of the American Economy*, Cambridge University Press, Cambridge, UK.

[2] For a discussion of the rapid rise of environmental issues on the international agenda see MacNeill, J., 1989–1990, The Greening of International Relations, *International Journal* XLV(Winter 1989–1990):1–35.

[3] In saying this, I do not mean to imply that all students of international relations share these views. For a particularly prominent exception see Bull, H., 1977, *The Anarchical Society: A Study of Order in World Politics*, Columbia University Press, New York, NY, USA. It is worth noting also that this critique of international society centers on what students of international affairs refer to as "third image" arguments – Waltz, K.N., 1959, *Man, the State and War: A Theoretical Analysis*, Columbia University Press, New York, NY, USA.

[4] For a well-known expression of the "world peace through world law" perspective see Clark, G. and Sohn, L.B., 1960, *World Peace Through World Law*, Harvard University Press, Cambridge, MA, USA. A sophisticated account of the logic of functionalism and neo-functionalism can be found in Haas, E.B., 1964, *Beyond the Nation-State: Functionalism and International Organization*, Stanford University Press, Stanford, CA, USA.

[5] For a discussion of the role of the domestic analogy in studies of international relations see Suganami, H., 1989, *The Domestic Analogy and World Order Proposals*, Cambridge University Press, Cambridge, UK.

[6] Wolf, Jr., C., 1988, *Markets or Governments: Choosing Between Imperfect Alternatives*, MIT Press, Cambridge, MA, USA. For a powerful argument focusing on organizational rigidities that develop in long-established political systems see Olson, M., 1982, *The Rise*

and Decline of Nations: Economic Growth, Stagflation, and Social Rigidities, Yale University Press, New Haven, CT, USA.

[7] This perspective on social institutions reflects the work of those, like North and Thomas, who are major contributors to "neo-institutional economics." For an excellent survey consult Eggertsson, T., 1990, *Economic Behavior and Institutions*, Cambridge University Press, Cambridge, UK. For an application of this school of thought to international relations see Yarborough, B.V. and Yarborough, R.M., 1990, International Institutions and the New Economics of Organizations, *International Organization* **44**(Spring 1990):235–259.

[8] For a sophisticated argument that this is true, even in the realm of security affairs, see Jones, D.V., 1991, *Code of Peace: Ethics and Security in a World of Warlord States*, University of Chicago Press, Chicago, IL, USA.

[9] The concept of "governance without government" is developed at length in Rosenau, J.N. and Czempiel, E.-O., eds., 1992, *Governance without Government: Order and Change in World Politics*, Cambridge University Press, Cambridge, UK. See also Kindleberger, C.P., 1988, *The International Economic Order: Essays on Financial Crises and International Public Goods*, Chapter 9, MIT Press, Cambridge, MA, USA.

[10] For a review of the recent literature on common property resources that discusses this question consult Field, B.C., 1990, The Economics of Common Property, *Natural Resources Journal* **30**:239–252.

[11] For a discussion of such roles see Young, O.R., Forthcoming, International Organizations Perspective, Chapter 14 in G. Sjosted, ed., *International Environmental Negotiation*, Sage Publications, Newberry Park, CA, USA.

[12] For a sophisticated account of governance systems applicable to the human use of common property resources in small-scale societies see Ostrom, E., 1990, *Governing the Commons: The Evolution of Institutions for Collective Action*, Cambridge University Press, Cambridge, UK.

[13] For an introductory account see Soroos, M.S., 1988, The International Commons: A Historical Perspective, *Environmental Review* **12**(Spring 1988):1–23.

[14] Demac, D.A., ed., 1986, *Tracing New Orbits: Cooperation and Competition in Global Satellite Development*, Columbia University Press, New York, NY, USA.

[15] For a collection of essays on this theme that includes Hardin's seminal essay entitled "The Tragedy of the Commons", see Hardin, G. and Baden, J., eds., *Managing the Commons*, W.H. Freeman, San Francisco, CA, USA.

[16] For an explicit effort to apply this logic at the international level see Eckert, R.D., 1979, *The Enclosure of Ocean Resources: Economics and the Law of the Sea*, Hoover Institution Press, Stanford, CA, USA.

[17] For a case study see Young, O.R., 1982, The Political Economy of Fish: The Fishery Conservation and Management Act of 1976, *Ocean Development and International Law* **10**:199–273.

[18] For an extensive discussion of international regimes pertaining to wildlife see Lyster, S., 1985, *International Wildlife Law*, Grotius Publishers, Cambridge, UK.

[19] For an interesting case in point see Richardson, E.L., 1988, Jan Mayen in Perspective, *American Journal of International Law* **82** (July 1988):443–458.

[20] Golubev, G.N., Forthcoming, Availability and Quality of Fresh-Water Resources: Perspective from the North, in O.R. Young, G.J. Demko, and K. Ramakrishna, eds., *Global Environmental Change and International Governance*.

[21] These resources possess what economists have come to regard as amenity value in contrast to commodity value. See Krutilla, J.V. and Fisher, A.C., 1975, *The Economics of Natural Environments: Studies in the Valuation of Amenity and Commodity Resources*, Johns Hopkins University Press, Baltimore, MD, USA.

[22] See Conca, K., Environmental Protection, International Norms, and National Sovereignty: The Case of the Brazilian Amazon, paper prepared for the Dartmouth College/United Nations University Conference on Sovereignty and Collective Intervention, May 1992, Unpublished.

[23] See Sagasti, F.R. and Colby, M.E., Forthcoming, Eco-development Perspectives in Developing Countries, in N. Choucri, ed., *Global Commons: Environmental Challenges and International Responses*, MIT Press, Cambridge, MA, USA.

[24] For some striking illustrations see Hurrell, A., Forthcoming, Brazil and the International Politics of Amazonia Deforestation, in A. Hurrell and B. Kingsbury, eds., *The International Politics of the Environment: Actors, Interests and Institutions*, Oxford University Press, Oxford, UK.

[25] For an interesting account stressing circumstances under which parties may not want to articulate the rules of the game in a legally binding form see Lipson, C., 1991, Why are Some International Agreements Informal? *International Organization* **45**(Autumn 1991):495–538.

[26] For a discussion of the concept of a constitutional contract see Buchanan, J.M., 1975, *The Limits of Liberty: Between Anarchy and Leviathan*, University of Chicago Press, Chicago, IL, USA, especially Chapter 4. The idea of institutional bargaining, as applied to international affairs, is developed in Young, O.R., 1989, The Politics of International Regime Formation: Managing Natural Resources and the Environment, *International Organization* **43**(Summer 1989):349–375.

[27] For a seminal account of integrative, in contrast to distributive, bargaining see Walton, R. and McKersie, R.B., 1965, *A Behavioral Theory of Negotiations*, Chapters 2–5, McGraw-Hill, New York, NY, USA. The idea of a "veil of uncertainty" is discussed in Brennan, G. and Buchanan, J.M., 1985, *The Reason of Rules: Constitutional Political Economy*, Chapter 2, Cambridge University Press, Cambridge, UK.

[28] For surveys of the major ideas see Haggard, S. and Simmons, B.A., 1987, Theories of International Regimes, *International Organization* **41**(Summer 1987):491–517; and Young, O.R. and Osherenko, G., eds., Forthcoming, *Polar Politics: Creating International Environmental Regimes*, Chapter 1, Cornell University Press, Ithaca, NY, USA.

[29] Young, O.R. and Osherenko, G., eds., Forthcoming, *Polar Politics: Creating International Environmental Regimes*, Chapter 1, Cornell University Press, Ithaca, NY, USA.

[30] For an extended discussion of the distinction between institutions and organizations see Young, O.R., 1989, *International Cooperation: Building Regimes for Natural Resources and the Environment*, Chapter 2, Cornell University Press, Ithaca, NY, USA.

[31] Young, O.R., Forthcoming, International Organizations Perspective, Chapter 14 in G. Sjosted, ed., *International Environmental Negotiation*, Sage Publications, Newberry Park, CA, USA.

[32] For the reflections of a prominent practitioner on these questions see Sand, P.H., 1990, *Lessons Learned in Global Environmental Governance*, World Resources Institute, Washington, DC, USA.

[33] For a particularly well-known expression of this view see Strange, S., 1983, "Cave! hic dragones": A Critique of Regime Analysis, in S.D. Krasner, ed., *International Regimes*, pp. 337–354, Cornell University Press, Ithaca, NY, USA.

[34] For some initial results see Young, O.R., Demko, G.J., and Ramakrishna, K., eds., Forthcoming, *Global Environmental Change and International Governance*.

[35] For an initial cut at this set of issues see Keohane, R.O. and Nye, J.S., 1989, *Power and Interdependence*, 2nd edn., Scott, Foresman, Glenview, IL, USA.

[36] In this connection, see Cox's account of the roles of material capabilities, institutions, and ideas: Cox, R.W., 1986, Social Forces, States and World Orders: Beyond International Relations Theory, in R.O. Keohane, ed., *Neorealism and Its Critics*, pp. 204–254, Columbia University Press, New York, NY, USA.

[37] The initial idea for such a network arose during the course of a conference on "Global Environmental Change and International Governance," sponsored by the United Nations University, Dartmouth College, the World Resources Institute, and the Woods Hole Research Center, and held at Dartmouth in June 1991. For a summary of the conference's conclusions and recommendations see Young, O.R., Demko, G.J., and Ramakrishna, K., 1991, *Global Environmental Change and International Governance: Summary and Recommendations of a Conference held at Dartmouth College, Hanover, NH, June 1991.* Copies available from the Nelson A. Rockefeller Center for the Social Sciences at Dartmouth College.

[38] While scholars are typically eager to engage in this sort of discourse, practitioners often lack the time and sometimes the inclination to contribute to such dialogues. However, for some thoughtful recent contributions from practitioners to our understanding of international environmental governance see Sand, P.H., 1990, *Lessons*

Learned in Global Environmental Governance, World Resources Institute, Washington, DC, USA; Benedick, R.E., 1991, *Ozone Diplomacy: New Directions in Safeguarding the Planet*, Harvard University Press, Cambridge, MA, USA; and Lang, W., 1991, Is the Ozone Depletion Regime a Model for an Emerging Regime on Global Warming? *UCLA Journal of Environmental Law and Policy* **9**:161–174.

[39] While it is unlikely that analysts will come up with indices as precise and operational as those used to assess the performance of individual firms in market economies, the gradual refinement of institutional indicators to monitor the performance of environmental governance systems would greatly enhance our ability to design and operate such systems successfully in the future.

PART VI

Population Growth and Aging: A Burden on Development

CHAPTER 10

Population Growth in the Third World

Léon Tabah

During the next 35 years the world will be the object of an unprecedented demographic evolution with considerable economic and social consequences, as well as impacts on the environmental resource base upon which sustainable development ultimately depends.

According to the United Nations' (1989, 1991) and to the World Bank's (1991) demographic projections, we have started to witness a genuine change in the world with the beginning of what is called the demographic transition of the Third World countries, that is, their progression into a phase of declining fertility accompanying declining mortality.

The generations born since the early 1960s will experience during their young and adult life an upheaval in the world demographic map owing to the inevitable staggering of the entry of the Third World countries into the transition phase, which, obviously, will not happen at the same time and at the same pace in all countries. Some countries, notably those in Africa south of the Sahara, have scarcely begun the process, and it would indeed be superficial to view this as merely "historical backwardness", while in almost all other countries the transition is rushing ahead so fast that the end of the process will be reached two or three times quicker than for many developed countries in the 19th, and up to the beginning of the 20th, century.

This passage through the demographic transition signifies that quantitative changes in the population would occur with qualitative transformations that would entail extensive repercussions on the world economy and on the environment. One wonders whether, for the first time, population growth would be intimately associated in the Third World with more "affluence", and whether the theory of transition – a major demographic theory – should not be entirely revisited. Or, to phrase this basic question another way: to what extent will the demographic transition of the Third World bring about subsequent increased demand for energy, food, and water, and to what extent will it be linked with more stratospheric ozone depletion, greenhouse effects, and the global spread of air pollution?

One argument which arouses skepticism about the application of the theory of demographic transition in the Third World is that for the industrialized countries the process was a "silent revolution", extremely slow, and induced by the progress of education and general well-being, while in many Third World countries the process is occurring very fast, impelled by policies at governmental level with considerable exhortation from the mass media and without a significant advance in consumption. To take the example of China – one quarter of the entire Third World population – the abrupt decline in fertility has been accomplished essentially thanks to governmental measures and surveillance at the individual level. In all Asian countries, as well as in many Latin American countries, strong incentives toward family planning are playing a decisive role in fertility decline. If this reasoning is correct, the merit of population policies and of family planning programs should be recognized as permitting not only the acceleration of the demographic transition, and therefore a way of obtaining more quickly a lower population volume when the transition is complete, but also to accomplish this result with less industrialization and fewer detrimental effects in general on the environment. This is in contrast with the industrialized countries whose life-styles are the source of the primary risks to our common future. These countries have been the main beneficiaries of the wealth accumulated through the processes of economic growth that have produced environmental degradation and resource depletion.

It is not necessary to justify this assertion to consider that population growth is the only, or even the main, factor in the deterioration of the environment. Other factors also have an influence, especially the technologies utilized since the last world war and unequitable development, both of which have resulted in the worsening economic and social situation of the South, particularly since the 1970s.

Let us consider the population aspect first. In the second part of this chapter we will discuss the demographic outlook and its environmental consequences.

The Effects of the Population on the Environment

The question of finding out to what extent population growth and distribution create a distinctive impact on the quality of the environment has become extremely controversial. Surprisingly enough, the subject has not greatly attracted the scientific community of demographers. At the 1989 International Population Conference in New Delhi, there was no mention at all of the subject among the 89 papers presented and discussed. Only recently has a Committee of the International Union for the Scientific Study of Population been set up under the chairmanship of Professor J.I. Clarke. This deficiency in the demographic community is all the more regrettable as the global risks to the environment have their roots at the local level which would normally fall under the competence of local or national institutions. It is well known that the problems of managing local common property resources are closely linked with the problem of protecting the global commons, such as the atmosphere and the ocean. The survey made by the Preparatory Committee for the United Nations Conference on Environment and Development has shown that 70% of countries have identified environment and development problems associated with their population dynamics (UN, unpublished). Today, almost all countries have ministries or agencies for environmental policy design and implementation, backed by appropriate legislation (Sachs, unpublished).

An increasing number of economists consider that environmental consequences are not adequately recognized in economic accounts, and they are becoming interested in the environment factor as they start envisaging environmental resources as economic goods. The evaluation of net national product should include environmental resource use in the same way that it includes other goods and services. Environmental resources are increasingly becoming part of the standard economic thinking in a broad ecological system whose carrying capacity is far from being infinite. See, for example, Partha Dasgupta and Karl-Goran Maler (1990) and Nathan Keyfitz (1989).

Before now, it has been difficult to assess the scope and scale of the linkages at work between population and the environment, and how they operate. One reason is that the necessary environmental data are generally absent, especially for developing countries. We have not reached the situation in which we are actually able to trace the causalities between population, environment, resources, and development. Therefore, it is not surprising that extreme views on the subject are rife.

Some authors have concluded that population growth is an essential, and even dominant, factor in environmental deterioration: P.R. Ehrlich and A.H. Ehrlich (1990); National Academy of Sciences (forthcoming); N. Myers (1991, forthcoming); R.E. Bilsborrow (forthcoming); and others. According to these authors, population pressures constitute a determining factor among many others. The three factors of population, consumption, and technology interact on the environment in a multiplicative fashion with other factors such as socioeconomic inequities, cultural constraints, government policies, and the international political order. Each of the three factors reinforces the others' impacts, but the role of the population is bound to be significant, even when population growth is relatively restricted.

N. Myers gave some illustrative examples in support of his assertion. During the 1970s and the 1980s, the amount of per capita arable land declined by 1.9% a year due to population growth surpassing the expansion of arable land, and this led to the application of fertilizers and pesticides to cope with the growing needs of a growing population. Consequently, there was a deterioration in the resources base.

Myers estimated that grain gained from the effects of the Green Revolution – the use of irrigation, fertilizers, and other inputs – was worth 29 million tonnes a year, equivalent to the total world requirement needed to feed the increase in population (28 million tonnes at current nutritional levels), while the total loss from all forms of environmental degradation adds up to 14 million tonnes of grain output a year. The emission of carbon dioxide is estimated to have been 2.4 billion tonnes in 1950, and at least 6.8 billion tonnes in 1985, with an average increase of 3.1% a year. As the rate of population growth was 1.9% annually, Myers drew from these figures the conclusion that population was responsible for two-thirds of the increase in carbon dioxide emissions, while the "affluence" and technology factors were jointly responsible for only 1.2% a year.

According to a recent study by the OECD (1991), at present, 30% of carbon dioxide emissions are produced by developing countries and 70% by industrialized countries. It is likely that these proportions will be reversed by the end of the first quarter of the next century, according to the US Office of Technology Assessment (1990), due to the population growth of the Third World on one side and the measures of environmental conservation taken by the industrialized countries on the other side. If this comes true, it signifies that environmental problems, mostly caused by today's industrialized countries, will change to being essentially caused by today's Third World.

Concerning the emission of methane, which cannot be as readily reduced as carbon dioxide emissions, its production is bound to increase with population growth since it comes from rice paddies, ruminant livestock, biomass burning, and natural gas, which are all expected to expand with the increased food needs of the growing population and dietary upgrading. To cater for increased food needs, land productivity should increase by 50% in developing countries by 2025 according to L.A. Paulino (1986), cited by Myers. Yet, in many parts of developing countries, especially Africa as a whole, food productivity has been contracting because of land degradation and poor agricultural planning.

The Third World currently produces 17% of global chlorofluorocarbons (CFCs), one of the main ozone-depleting chemicals, but with the growing demand for refrigerators, one of the major products using CFCs, the Third World would expand CFC production ten-fold as a response to the effect of population growth and to ameliorate living conditions. Nonetheless, we might anticipate that the expected increase in the number of refrigerators in the Third World will be due more to reducing the backwardness of the level of consumption than to population growth.

We have to acknowledge that the population factor is playing an important role in deforestation due to the need for cheap energy and the practice of slash-and-burn by landless farmers. According to J.C. Allen and D.F. Barnes (1985), an increase of 1% in population is associated with an increase of 0.5% in deforestation in the Third World. If their econometric analysis is correct, it means that in all developing countries the deforestation rate is about 1% a year, which is extremely high. As a matter of fact, this is only an average: in Africa the rates are much higher in countries such as Nigeria (14%) or Ivory Coast (15%). The two main proximate causes of deforestation in the Third World are new agricultural settlements on increasingly marginal lands and the high cost of energy leading to the use of fuelwood (R. Bilsborrow, 1992), while the ultimate causes are population growth and poverty. A study by the FAO (1991), based on a statistical analysis for 60 developing countries, concluded that population growth is significantly associated with deforestation. The future is not promising: according to UN demographic projections almost 80% of the population in 2025, some 6 billion inhabitants, are expected to be living in tropical areas of the world, putting pressure on the remaining forests.

The impact of population growth and redistribution, especially the absolute increase in the number of people each year and migration to cities, are also playing a direct substantial part in water shortages. It is already estimated that as many as two billion people live in areas with chronic shortages, where the water is often contaminated by pollutants and pathogenic agents. Human consumption of water has doubled this century, and it will at least double again with the population growth during the next three decades (Falkenmark, 1990; Commoner, 1991, forthcoming). If the analysis of the authors convinced of the responsibility of the population factor in the deterioration of the environment were confirmed, the resolution of environmental degradation should rest, at least partly, with the control of population growth, therefore, essentially, in the Third World.

Barry Commoner (1991, forthcoming), also in search of the respective influence on environmental quality of the three factors of population, consumption, and technology, reached the opposite conclusion. Discussing, through decomposition analysis, the number of automobiles as an indicator of the pollutants emitted in 65 developing countries over the period 1970–1980, he found that in the annual rates of change of the environment the population was responsible for 2.5%, affluence for 0.2%, and technology for 5.4%. In sharp contrast to the authors mentioned previously [Ehrlich and Ehrlich (1990); National Academy of Sciences (forthcoming); Myers (1991, forthcoming); Bilsborrow (forthcoming)], Commoner concluded that the influence of technology on the environmental impact is more than twice as high as the influence of the population factor. He arrived at similar conclusions concerning the production of electricity (effect of population, 2.7%; average annual change in GDP per capita, 0.7%; average annual change in electricity with respect to GDP, 8.1%) and concerning the impact of nitrogen fertilizer (population effect, 2.5%; agricultural production per capita, -0.6%, nitrogen use per unit of agricultural production, 6.6%). In all these calculations, the effect of population seems in harmony with the rate of population growth, while the effects of the two other factors - consumption and technology - are essentially dependent on the nature of the technology used. What is surprising in this analysis is the very low, or even negative, impact of the consumption factor. We will see later that it might be very different in the future with the deployment of the population transition.

Whatever the quantitative impact of the population on the environment may be, two conclusions emerge from the literature. First, population growth is not the sole force that undermines the environmental resource base, but one among others, one particularly important factor being the technology used. What does vary according to different studies is the respective share of responsibility each factor accounts for: we should recognize that the statistical tools available to deal with this basic question are extremely rudimentary. Secondly, the three factors (population, consumption, and technology) interact in a multiplicative fashion, and it is these interactions that will matter in the future as the last two factors increase their influence. Environmental economics and population growth and distribution will be tied to each other in an intricate web.

Let us turn now to the time horizon, as we can assume that the next four decades will definitely witness a different demographic path from the past. As the populations of most of the Third World, except the sub-Saharan area, are entering a period of lower fertility rates, with growth rates nonetheless extremely high by historical standards, the interactions of population and the two other factors will exercise their full strength, unless two conditions are met, jointly or independently. These two conditions are that:

- The development of the Third World will be achieved in a different way than for the industrialized countries, with alternative options using "clean technologies".
- The decline in fertility will not be accompanied by much affluence, contrary to the theory of demographic transition, as was experienced in the past by the industrialized countries when concern for the environment was practically non-existent.

Concerning the first condition, we should recognize that some growth in the use of energy by developing countries is inevitable, and, at present, development scenarios for these countries follow the same material-intensive patterns as the industrialized countries. As a matter of fact, the economies of Third World countries that are experiencing strong economic growth are all adopting an energy-intensive, heavy industrialization phase. This is the case in Korea, Taiwan, the countries that belong to the Association of Southeast Asian Nations (ASEAN), and, more recently, Turkey, Mexico, and Brazil. In 1950, there were 6,000 factories in Taiwan: the number is now around 100,000. Last summer (1991), the standard index of pollution in the industrial center of Hsinchu reached a level which was twice as much as that during the worst days in Los Angeles.

Bangkok, Peking, and Manila rival Taipei as regards pollution. Throughout the whole of Asia measures for safeguarding the environment are absent or ignored. The decision makers consider that the costs of environmental protection are too high and that they are having constraining effects on their development strategies. In all developing countries, development concerns surpass environmental ones, at least for the time being. Preventing soil degradation at village level has less priority than increasing food production to feed a growing population. Besides, the poor, in general, do not have the means to undertake soil conservation measures that would preserve their resources. Their first task is to meet immediate basic human needs. To do so, they are often compelled to overexploit the natural resources on which their long-term development depends.

Preventing carbon dioxide emissions by restricting automobile transport in cities like Mexico, Cairo, Bangkok, Rio de Janeiro, or Sao Paulo is attempting the impossible. Exerting pressure on developing countries to shift to environmentally sound technologies is putting a burden on the economies of those countries. At the present time, the technologies of industry, agriculture, and transportation are basically the same in developing countries as they are in rich countries, but developing countries do not have the necessary resources for the adoption of measures to protect the environment. It is very unrealistic to request developing countries to take preventive measures against environmental pollution by abandoning the production technologies that generate it. As the Brundtland Commission stated in 1987: "The industries most heavily reliant on environmental resources and most heavily polluting are growing most rapidly in the developing world where there is more urgency for growth and less capacity to minimize damaging side effects." It is therefore irresponsible to call for "environmental protection" without assessing what effects such protection will have on the economic activities of the Third World.

Besides, the industrialized countries themselves have not been able to make changes in technologies adopted since the 1950s: use of inorganic nitrogen fertilizers, synthetic pesticides, synthetic petrochemical products, truck freight, etc. They are not ready to return to earlier, less productive technologies until new, safe technologies are devised. It is generally recognized that nuclear energy is creating problems, as a matter of fact not unexpected, and that the present nuclear plants are aging badly, thus requiring additional cost for their maintenance. There is growing concern about the costs of nuclear waste disposal: there is no real solution at present. It is estimated that 800,000 children have been affected by the Chernobyl catastrophe. More than 600,000 hectares of land and forest in the region are unexploitable for a very long period. The demographic consequences of Chernobyl in the areas of the catastrophe have been discussed recently and openly by Rybakovsky (forthcoming): these are a decline in fertility, concerns about a likely increase in morbidity and mortality, and desertification of large areas. It was a national disaster and any repetition could have an international dimension.

If it is true that industrialized countries contribute more to environmental damage than the developing countries, then the latter also suffer more than the former. The Bhopal catastrophe is a case in point which, unfortunately, is bound to be repeated in developing countries if industrialization occurs without the necessary financial needs. The Brundtland Commission stated that the common need for global environmental security requires a substantial and sustained increase in the flow of financial resources to support the broad development needs of developing countries.

The main question is: is the date for reaching the end of the population transition too close to permit most current technological constraints to be overcome? At this stage, is it likely that expansion of agricultural production will be feasible on a world scale without dire environmental effects if present technologies, such as those of the "green revolution", are modified? We should remember that, in Asia, an increase in agricultural production is possible only through increased productivity, rather than through an increase in arable areas. Is it likely that the industrialization of the world will be accomplished with clean energy technologies before long?

The Demographic Outlook and its Environmental Implications: an Open-ended Demographic Future

The world's future in demographic terms would seem to be very open-ended, judging by the United Nations' projections, since the high and low population variants put the population in 2025 at 9.42 and 7.59 billion respectively, i.e., a difference of 1.83 billion. The actual figure will probably lie somewhere between the two. However, it is obviously not a matter of indifference whether it will be closer to one or the other as far as resources and the environment are concerned, even if 91% of this 1.83 billion difference were accounted for by today's developing countries and only 9% by today's developed countries, which consume more raw material and cause more environmental pollution. It is true, on the other hand, that a large number of developing countries are also responsible for damage to the environment as a result of poverty, and many of them will progressively experience a form of development, as we will comment on now.

The growing diversification of the Third World

Many of today's developing countries are and will be moving into the category of industrialized countries. We are witnessing a demographic diversification in the Third World. The simple two-speed pattern of population growth of 20 years ago has been superseded by one that is increasingly varied. All the signs are pointing to a world where demographic change takes place at several speeds and gives rise to a vastly different geographic distribution of its population. The idea of a North-South demographic divide is no longer valid, as can be seen from both the United Nations' and World Bank projections. It is equally obvious that, at the same time, we are beginning to see the end of a pattern of economic development at two or three speeds. The world scene is becoming even more varied, and one where today's developing countries will move in different directions, with some rapidly catching up on the industrialized countries from both the demographic and the social and economic standpoints.

The "old Third World" is split into diverse degrees of successful developers and the rest: and, looking at this more closely, it is obvious that those countries which are quickest in accomplishing the demographic transition are the ones which are in the best position in terms of international competition. Take the example of the "four dragons" so often referred to: they are now well into the post-demographic transition phase and there is little or no difference between them and the countries of Western Europe in terms of both fertility and mortality. In the radical changes that are beginning to occur within the hierarchy of world powers it is clear that countries that were for a long time considered as underdeveloped will soon be up among the leaders. It is equally clear that while accomplishing the demographic transition will not in itself ensure development, without this demographic transition development in the Third World is inconceivable, even in a soft form, as we will discuss later on.

A persisting poverty

Although the idea of an "ever-widening divide", so widely accepted during the 1950s and 1960s, is by no means a thing of the past, the divide is no longer simply between the whole of the North and the whole of the South, but between the North plus a substantial part of the South on one side, leaving on the other side large black spots that are likely to persist for a good many years to come. These latter areas include almost all of sub-Saharan Africa, where under-exploitation of natural resources, compounded by totally unrestrained population growth, political unrest, and environmental damage, is isolating this subcontinent from the world economy.

In Asia, which comprises the most heterogeneous collection of countries from both the economic and demographic standpoints, the future of many populations looks scarcely more hopeful. Alongside the dramatic success stories there are, according to the World Bank, 600 million people living in "absolute poverty". This means not only low income and malnutrition, but also lack of access to education, health care, housing, drinking water, and main drainage. This poverty is rife not only in Bangladesh, Myanmar, Pakistan, Afghanistan, and Cambodia, but also in countries where the overall situation is beginning to improve, as in the Philippines (where it is estimated that 35% of the total population live in poverty) and Sri Lanka. In India it is reckoned that 40% of the population, and, more particularly, the inhabitants of the northeastern states, are below the poverty line. In China 130 million people, mainly in rural areas, are known to be living in penury.

In short, it can be said that a substantial proportion of the Third World's inhabitants, an estimated 1 billion at least, are untouched by the process of development and, since this vast population has not yet gone through a process of genuine demographic transition, the number is likely to double by the year 2025. In 1985 this proportion of the population accounted for 40% of the lowest income group (below $480 per head according to the World Bank), totaling an estimated 2.4 billion people. It is to be hoped, of course, that a proportion of this population will move out of "absolute poverty" before the number in that category doubles. The way world demography evolves will, to a large extent, depend on what the future holds in store for this vast section of the world population, since it is destined to have the most prolonged and highest growth rate. Its magnitude, constantly renewed, has been singularly resistant to reduction in all parts of the world and its persistence is beyond our comprehension.

Demographers, as well as environmentalists, are keeping a constant eye on the poorest of the poor. Demographers for the reasons we have just mentioned: environmentalists are also maintaining a strong interest in this fraction of the population because they consider that poverty and environmental degradation are closely linked, as are the opulence of industrialized countries and the environment, with the difference that the poor bear the brunt of the environmental damage while the rich have the resources to try to counteract it. The poor living in absolute poverty are dependent for their survival upon the environmental resources of soil, water, forests, fisheries, and biotics that make up their main stocks of economic capital. They have no alternative but to exploit their environmental reserve base at an unsustainable rate, causing irreversible injury, deforestation, desertification, and soil erosion on a wide scale.

It is well recognized that poor people are forced into ways of living which induce further destruction because of the complex cycles of poverty, inappropriate development, and environmental deterioration. In many countries most domestic energy comes directly from biomass resources. In some sub-Saharan countries, such as Burkina-Faso, Chad, Ethiopia, Malawi, Mali, Niger, Senegal, and Tanzania, wood accounts for 90% of the national energy consumption, even in rich, oil-producing countries such as Nigeria (Eckholm *et al.*, 1984). Urbanization is not mitigating the problem as urban consumption of wood is to be blamed as well as rural consumption. Some studies describe the surroundings of sub-Saharan cities as deforested "rings of desolation". According to G. Barnard and L. Kristofersen (1985), as the energy crisis worsens, a considerable proportion of the world population will be forced, in the near future, to consume wood faster than it is being grown, unless new sources of energy are made available to poor people.

It is women who are most affected by the consequences of environmental deterioration. There is a growing amount of literature on the subject, well summarized by I. Dankelman and J. Davidson (1988). Once again, we have to recognize that women are playing a central role in both population and environment.

The build-up of a momentum which will weigh heavy on the future

During the 45 or so post-war years, the world has built up a substantial growth momentum within its demographic structures as the result of a high birth rate during this period, as evidenced by the fact that, despite the slower growth rate, the absolute figure for world population will continue to increase for several decades. From 2.5 billion in 1950, the world population had doubled by 1987, will exceed 8.5 billion in 2025, and, according to the World Bank, is likely to be over 11 billion by the end of the next century. According to the United Nations' medium variant, the annual increase, 47.2 million in 1950–1955, rose to 80.7 million in 1980–1985, and will continue to rise to a peak of 95.5 million. It will not be until 2020–2025 that the annual increase will drop back to its 1980–1985 level. According to the high variant, the annual increase is likely to climb to a figure of 126.3 million by 2020–2025 before it begins to drop back.

In terms of individual countries a good example of this growth momentum is Kenya, which has one of the world's highest population growth rates (4.04% between 1985 and 1990 according to the United Nations' figures). Half of this growth can be calculated as being due to current reproductive behavior and the other half to past reproductive behavior.

As was said earlier, the UN projections are based on the assumption that each country in turn will reach a situation of zero growth. The World Bank has worked out the figures for these stationary populations, which in many cases are substantial multiples of the 1985 figures. Take the case of Algeria: the 1985 population was estimated at 21.9 million. The fertility rate is expected to fall from 5.9 for 1985–1990 to 2.1 for 2025–2030, with a population at that date of 57.8 million, but which would continue to increase up until 2100, by which time it would have reached the stage of a stationary population of 80.4 million.

It is interesting to compare the projections for Algeria and Tunisia. Algeria, which until 1985 had not managed to formulate a family planning program that had any real impact on fertility, is destined to see an almost four-fold increase in its population. In contrast, Tunisia, which as early as the mid-1960s adopted a policy that encouraged family planning, can expect its population to increase by "only" about two and a half times before reaching the stage of zero growth, which it will do over a shorter space of time (7.1 million in 1985 to 17.3 million in 2075). This is despite the fact that around the year 1960 these two countries had fairly similar birth rates. Algeria has recently decided to adopt a policy of "maîtrise de la croissance démographique" (control of demographic growth). However, a delay in adopting a population policy can cause insoluble problems, especially with a fragile environment characterized by insufficient water resources.

A relatively new phenomenon: migration due to environmental degradation

In the future there is likely to be a far higher level of migration from regions in the world with high population growth and low development into regions with the opposite characteristics, i.e., with a depressed demographic pattern but with very healthy economic development, particularly since, as recent years have shown, the former are in many cases politically unstable, thus prompting flows of workers and their families. The developed world will find itself with a diminishing and aging labor force and will be faced with a young and abundant labor supply in the Third World prepared to cross the ocean in search of work. Migration, in fact, is occurring between countries which are increasingly further afield, facilitated by increasingly less expensive means of transport. This is particularly true as regards Europe and the Southern and Eastern Mediterranean, where for the moment no real center of development is emerging, unlike in Asia and, to a certain extent, in Latin America. With the intensification of migration, internal or international, the human environment of most inhabitants will change drastically. The combination of differential fertility and international migration will also change the ethnicity distribution of the population.

In certain years, flows of migrants leave regions of the Third World depressed by environmental degradation and move toward other parts of the Third World, or of industrialized countries. More and more migration flows tend to ignore the borders of Third World or industrialized countries. Let us take one example, even if it might be considered as an extreme case: the Sahel region in Africa. In Mali, a demographic survey conducted in 1985 provided information on the causes of migration (Thiam, forthcoming): causes relating to drought accounted for 51.5%, compared with 45.7% related to work or study, and 28% for family or other reasons. There are good reasons to believe that the Mali case is only one among many others, one other case, in particular, being Brazil, and that with continuous environmental deterioration in the Third World the exodus could grow considerably. S. Ricca (1989) estimated that in 1983, 35 million Africans lived outside their countries of origin, i.e., 8% of the sub-Saharan African population, one of the highest figures compared with other large regions of the world. There are mass migrations into tropical countries due in part to both population growth and deforestation. N. Myers cited the cases of Colombia, Ecuador, Peru, Bolivia, Ivory Coast, Nigeria, India, Thailand, Vietnam, Indonesia, and the Philippines.

It is true that international migration, or migration among African countries, has been part of the African way of life for generations, pastoral nomadism being a distinguishing cultural feature of the African population, but an increasing number of environmental reasons are gaining significance. One of the most extreme and most striking cases is migration in the areas of the Chernobyl catastrophe. Rybakovsky (forthcoming) indicated that in the Kiev province, where the population got the information sooner than others, the positive balance of migration of 93,000 people in 1985 was replaced by a negative one of 49,000 in 1986: and many more inhabitants want to leave the affected areas, especially in the Gomel area of Belorussia. The economic factor is no longer the main cause of migration flows and the environmental one could reach a sizable dimension in the future.

The geographical distributions of populations within countries are far from optimal as regards resources and the environment. A percentage equal to 60% of the world population already live in coastal areas, and 65% of cities with populations above 2.5 million are located by the coast. This growth in coastal populations is exerting strong pressure on the marine environment and its resources, and this results in increasing sources of pollution, as sewage discharge effluent goes directly into near-coastal waters. As more than half humanity lives in coastal areas, the potential changes in sea level as a result of global warming should draw considerable attention, before they actually occur. Also, as a result of global warming intra-regional shifts in agricultural productivity, and consequently in geographical distribution of population, will possibly take place, a factor which is beyond any forecasts at this time. Some adaptation of the population will have to take place.

Ecological risks due to a combination of climatic changes, rapid urbanization, and high population density – and we will see that some densities in the Third World could reach high levels in the future because of population growth – could jeopardize life in many parts of developing countries, should natural catastrophes occur.

The prospect of demographic transition in the Third World

What are the prospects for world demography during the next decades according to the United Nations' and World Bank projections? When will the demographic transition be completed in these projections?

It can be reasonably assumed that the demographic transition will be completed, or approaching completion, when the total fertility rate (TFR) is 2.1, since this generally corresponds to a life expectancy which permits population replacement. This does not, however, imply zero growth, because of the time lag in the adjustment of the structure to fertility and mortality effects. For the world as a whole, the medium-variant United Nations' projection extrapolated to the year 2030 gives an aggregate TFR of 2.1, a growth rate of 1%, a 70-year life expectancy at birth (for both sexes), and a 70% rate of urbanization. At that time, the process of demographic transition would be almost completed in the Third World as a whole, the world would contain 7.1 billion inhabitants in the countries of today's Third World and 1.4 billion in today's industrialized countries.

As an indicator that a country is well on the way to completing its demographic transition, we selected a TFR of 2.5, rather than 2.1, because experience has shown that at that stage, although the country has not fully completed its transition, it is not far off, and it is well on its way along the path of economic, industrial, and social development.

Table 10.1 indicates when different countries are expected to attain a total fertility rate below 2.5. *Table 10.2* provides aggregate populations for major world regions at various dates, divided into two groups depending on whether the TFRs of the populations will at that time be above or below 2.5. Both sets of calculations are based on the United Nations' medium-variant projections. All the columns in *Table 10.2* concern today's developing countries, except for the two right-hand ones which show aggregates for today's

Table 10.1. The period during which a total fertility rate (TFR) below 2.5 will be reached for different countries.

1980–1985	1985–1990	1990–1995	1995–2000	2000–2010	2010–2020	2020–2025	Beyond 2025	
Mauritius	Reunion	Sri Lanka	Israel	Tunisia	Algeria	Cape Verde	Angola	Rwanda
China	Korea	Thailand	Surinam	Indonesia	Egypt	Ghana	Botswana	Senegal
Hong Kong	Guadeloupe	Guyana	Trinidad	Fidji	Morocco	S.Africa	Benin	Sierra Leone
Barbados	Uruguay	Jamaica	Turkey	Malaysia	Bahrain	Cambodia	Burkina F.	Somalia
Cuba				Vietnam	East Timo	Bangladesh	Burundi	Sudan
Martinique				Argentina	India	Jordan	C.Afr.Rep.	Tanzania
Puerto Rico				Chile	Kuwait	Iran	Cameroon	Togo
				Colombia	Myanmar	Laos	Chad	Uganda
				Costa Rica	Philippines	Nepal	Congo	Zimbabwe
				Mexico	Brazil	Pakistan	Comoros	Zaire
				Panama	Dominican Rep.	Un.Ar.Emirates	Djibouti	Afghanistan
					Ecuador		Eq.Guinea	Bhutan
					Peru		Ethiopia	Iraq
							Gabon	Mongolia
							Gambia	Oman
							Guinea	Qatar
							Guinea Bi.	Saudi Arabia
							Ivory Coast	Yemen
							Kenya	Bolivia
							Lesotho	El Salvador
							Liberia	Guatemala
							Libya	Haiti
							Madagascar	Honduras
							Malawi	Nicaragua
							Mali	Paraguay
							Mauritania	Venezuela
							Mozambique	
							Namibia	
							Niger	
							Nigeria	

Source: United Nations (1991), medium variant.

Table 10.2. Population projections (in millions).

		Africa	North Africa	South Sahara	Latin America	Carib-bean	Central America	Temperate America	Tropical America	Asia
1985	TFR > 2.5	553	123	430	390	17	105	45	223	1649
	TFR < 2.5	2	0	2	14	14	0	0	0	1065
	Total	555	123	432	404	31	105	45	223	2714
1990	TFR > 2.5	640	141	499	430	19	118	46	247	1780
	TFR < 2.5	2	0	2	18	15	0	3	0	1209
	Total	642	141	501	448	34	118	49	247	2989
1995	TFR > 2.5	745	159	586	471	18	131	48	274	1911
	TFR < 2.5	2	0	2	22	18	0	3	0	1376
	Total	747	159	588	493	36	131	52	274	3287
2000	TFR > 2.5	865	179	686	407	18	38	52	299	1810
	TFR < 2.5	2	0	2	131	21	107	3	0	1774
	Total	867	179	688	538	39	145	55	299	3584
2010	TFR > 2.5	1135	209	926	366	21	40	0	305	764
	TFR < 2.5	13	11	2	262	22	133	61	46	3344
	Total	1148	220	928	628	43	173	61	351	4108
2020	TFR > 2.5	1260	66	1194	158	25	49	0	84	848
	TFR < 2.5	192	190	2	559	23	151	66	319	3723
	Total	1452	257	1196	717	48	200	66	403	4571
2025	TFR > 2.5	1291	73	1218	184	26	54	0	104	228
	TFR < 2.5	306	201	105	573	24	159	70	320	4556
	Total	1597	274	1323	757	50	213	70	424	4784

Table 10.2. Continued.

		East Asia	Southeast Asia	South Asia	West Asia	Oceania	Developing countries	Industrial countries	World
1985	TFR > 2.5	63	402	1070	115	4	2596	0	2596
	TFR < 2.5	1065	0	0	0	0	1081	1174	2255
	Total	1128	402	1070	115	4	3677	1174	4851
1990	TFR > 2.5	3	445	1201	132	5	2855	0	2855
	TFR < 2.5	1209	0	0	0	0	1229	1207	2436
	Total	1212	445	1201	132	5	4084	1207	5291
1995	TFR > 2.5	3	430	1328	151	5	3132	0	3132
	TFR < 2.5	1297	60	18	0	0	1400	1236	2636
	Total	1300	490	1346	151	5	4532	1236	5768
2000	TFR > 2.5	4	231	1477	105	5	3087	0	3194
	TFR < 2.5	1378	304	19	67	1	1908	1264	3065
	Total	1382	535	1496	172	6	4995	1264	6259
2010	TFR > 2.5	4	83	546	132	6	2271	0	2271
	TFR < 2.5	1481	533	1245	85	1	3620	1310	4930
	Total	1485	616	1791	217	7	5891	1310	7201
2020	TFR > 2.5	6	25	649	169	7	2273	0	2273
	TFR < 2.5	1566	666	1395	95	1	4475	1342	5817
	Total	1572	691	2044	264	8	6748	1342	8090
2025	TFR > 2.5	5	4	44	176	0	1703	0	1703
	TFR < 2.5	1604	722	2118	112	8	5443	1354	6797
	Total	1609	726	2162	288	8	7146	1354	8500

Source: United Nations (1991), medium variant.

industrialized countries and for the whole world respectively. The regions are those used in the United Nations' projections.

At the beginning of the projection period, in 1985, few Third World countries, other than China, had a TFR below 2.5 (as can be seen from *Table 10.1*). They were mostly countries with relatively small populations, below 5 million: Mauritius, Hong Kong, Barbados, Cuba, Martinique, and Puerto Rico. Between 1985 and 1990, the four countries which entered this group (apart from South Korea with 44 million inhabitants in 1990) are once again of limited population size, and the same can be said of those added between 1990 and 1985: Sri Lanka, Guyana, Jamaica, and Thailand. It is toward the end of the century that countries with large populations – mostly in Asia – begin to appear in the low-fertility group: Turkey in 1995–2000, Tunisia, Indonesia, Fiji, Malaysia, Vietnam, Argentina, Chile, Colombia, Costa Rica, Mexico, and Panama in 2000–2010. Then, between 2010 and 2020, many countries make their entry: countries from North Africa (Algeria, Egypt, Morocco), Latin America (Brazil, Dominican Republic, Ecuador, Peru), or Asia (Bahrain, East Timor, India, Kuwait, the Philippines, Myanmar). At the end of the projection period (2020–2025) we find three African countries (Cape Verde, Ghana, South Africa), some from the Near East (Iran, Jordan, United Arab Emirates), and, above all, Bangladesh, Pakistan, and Cambodia.

Nonetheless, by the year 2025 a long list of developing countries will still be a long way from completing their demographic transition: 40 African countries, 8 Latin American countries, and 8 Asian ones (5 of them in the Near East). At the turn of the century, almost all Asian countries and much of Latin America should consequently be well on the way to completing their demographic transition, while sub-Saharan Africa and part of the Near East will still be a long way off. According to the World Bank estimates, we cannot expect TFRs of around 2.5 for a large part of sub-Saharan Africa until the year 2050. Moreover, this is only an average, and a considerable number of African countries would still have TFRs exceeding three: Niger, Malawi, Rwanda, Mali, Mauritania, Gambia, and Sierra Leone.

What is striking is that between now and the year 2025 – a mere 35 years – the population of the countries which will have completed, or almost completed, their demographic transition will amount to almost 6.8 billion, or 5 times that of today's industrialized countries (*Table 10.2*). Thirty-five years is an excessively short period for a transformation of such amplitude, given that the countries concerned will also be by then somewhat industrialized and highly urbanized. A much longer time was necessary for today's industrialized countries to come to the end of the demographic transition process, and become both industrialized and urbanized. It seems an impossible challenge for the Third World, and the world as a whole, if the international community does not fundamentally change its ways of reacting and thinking, in particular from the environmental standpoint. Production, whether industrial or agricultural, should be conducted so as not to weaken or diminish our planet's capacity to sustain life, and to protect our environment in both the present and the future.

Doubts about the demographic outlook

Should the United Nations' and the World Bank projections be realized, there will be many more areas of development and environmental crises in the future. The crises could be such that they cast doubts on the materialization of the projections. Some distortions would necessarily occur, such as different trends in fertility, fewer improvements in health and mortality, and intensification of migration. One feature of these projections which leaves them open to doubt is that they are presented as if they were vectors unaffected by any external factors, proceeding in a vacuum without any hindrance. They are not endogenized. It is this that makes them scarcely credible as soon as they go beyond one or two decades. One certainty is that each of the factors of population, environment, and food and energy has assumed global significance and interacts closely with the others.

The second reason for doubt is that it is not conceivable that some form of demographic equality will gradually emerge at the end of the demographic transition, given that the end of the transition will apply not only to the world population as a whole, but also to that of each individual country. It is difficult to accept this idea since it would imply either that people will become equal in terms of economic and social conditions, or that differences in economic, social, and even cultural conditions will no longer have any effect on either fertility or mortality. So far, however, no hypothesis of any other kind has been put forward, and perhaps, therefore, for want of anything better, we can accept the idea, provided the calculations are not extended too far into the future, following the example set by the United Nations.

A third serious doubt as regards these projections is the seeming implausibility of many of the results. For example, is it conceivable that Africa, with its many ecological and economic problems, where school enrollment rates and the number of doctors are the lowest in the world, where industry is limited and where there is a growing division between vast urban conglomerations and immense tracts of derelict land, is likely to see its population increase seven-fold between 1950 and 2025, and thirteen-fold between 1950 and the end of the next century? The population of Africa, which represented less than 10% of the world population in 1950, would rise to a level where it formed over 25% of the world population. This would be the case unless, of course, it is assumed that there would be massive emigration, a hypothesis which demographers working in international organizations have not dared to put forward; or that mortality rates would cease to decline and would even rise as a result of the worsening of nutritional and economic conditions, the emergence of new diseases such as AIDS, or the resurgence of illnesses such as malaria or cholera; or that there would be a combination of all these adverse circumstances – something that cannot be ruled out, at least in certain regions.

Is it likely that the Sahel countries (Burkina Faso, Chad, Gambia, Mali, Mauritania, Niger, and Senegal) will see their populations increase four-fold, on average, between 1985 and 2025, and by almost as much again between 2025 and the end of the next century? The population of Ethiopia, which has been going through one famine after another over the last 20 years, is forecasted to increase three-fold between 1985 and 2025, and by as much again by the end of the century. Rwanda's population density is expected to rise from 232 per km^2 in 1985 to 841 per km^2 in 2025, and to double by the end of the century. In Nigeria, where (according to the FAO) the carrying capacity of the land is already very limited, the population density is forecasted to triple between 1985 and 2025, when the population would be 300 million, that is to say, virtually, the same as the present population of western, southern and northern Europe combined. In Bangladesh, the population density already exceeds 800 per km^2, but the figure is expected to reach 1,600 by 2025 and close to 3,000 during the course of the next century. The population of Algeria, where there is concern about the available water resources and reserves, is forecasted to double between now and the year 2025, and to rise by at least a further 40% during the next century. There are many other examples which could be quoted that cast doubt on the projections, particularly when they are taken too far, but which nonetheless are valuable in demonstrating that deviations in trajectories are bound to occur and that an attempt should be made to envisage these.

The paradox with these projections is that the populations forecasted to expand most rapidly in the future are precisely those that are being subjected to the strongest demographic pressures, and which for a number of decades have been confronting problems that they are unable to solve and that are getting worse. Admittedly, it has been true that, until now, the poorer a population was, the faster its growth. However, tomorrow's world is unlikely to be a repetition of yesterday's, and it is very probable that populations facing difficulties, because of the deterioration of their environment, for example, will try to move into less hostile surroundings: in fact, we are already beginning to see migratory movements in Africa and Brazil caused by deterioration of the environment, as was said earlier.

A fourth source of doubt regarding the population projections is just how quickly birth control will become widely practised in the poorest parts of the Third World, especially sub-Saharan countries, and it is this which leads us to believe that, for these countries, the high rather than the low variant of the United Nations' projections is likely to be closer to the truth.

The medium-variant projections forecast that the fertility in Africa between 1990–1995 and 2020–2025 will drop from 6.00 to 3.05 – in other words a far sharper fall than occurred in India, despite persistent unsuccessful governmental dissemination of contraceptive methods over the last few decades. It seems likely that the more plausible hypothesis for Africa will be the high-variant projection which forecasts a drop in the fertility rate from 6.32 in 1985–1990 to 3.96 in 2020–2025, rather than the medium-variant figure of 3.05. The low-variant projection of a drop in the fertility rate to 2.45 (the rate of the industrialized countries 20 years ago) would seem to be quite unrealistic. Unfortunately, for mortality the assumptions for Africa as a whole should also be taken to be at the high level. We will come to this point later.

The United Nations' and World Bank projections for a relatively steep decline in fertility rate in sub-Saharan Africa and the poorest regions of the Third World are only likely to be proved correct if recourse to contraception were to change. So far, the use of contraceptive methods has been conditional on their acceptance, determined to a great extent by the improvement in women's status and level of education, and the more general improvement in living conditions. It is not inconceivable that we may see the development of what might be termed "contraception for poor people". It is not inconceivable that a fertility transition may take place in response to economic hardship, as was suggested for sub-Saharan Africa by E. Boserup (1985), helped by large-scale campaigns to promote birth control using ever-more powerful and wide-reaching mass media. It is virtually certain that the future will see the introduction of cheap, modern methods of contraception which are within the reach of even the poorest members of society, and that the current inhibitions about their use will gradually disappear. Such publicity campaigns are already being waged vigorously in Asia, Latin America, and even in Africa north of the Sahara: in contrast, to the south of the Sahara they are still timorous or even non-existent. It should also be mentioned that governments have never been as convinced as they are now of the need to contain population growth when it is unduly high. In this respect, considerable progress has been made since the first major policy conference on the subject, held in Bucharest in 1974, and even since the one held in Mexico in 1984.

Concern about health and mortality, especially in sub-Saharan Africa

A fifth area of doubt and concern about the projections of the UN and the World Bank concerns the mortality trends, about which five points may be made:

- It is suspected that there has been an increase in mortality rates in tropical countries. It is virtually certain that malaria is staging a strong comeback: there is a clear and steady rise in the incidence of this disease. The World Health Organization estimates that there are no less than 1.7 billion inhabitants of tropical regions facing the threat of malaria, because the situation there is unstable and getting worse (WHO, 1990). The latest estimates put the current number of malaria cases per year throughout the world at 100 million and the number of carriers of the parasite at 264 million, mostly on the African continent and in Central and South America, particularly Amazonia. In some countries where the disease is rife, such as Nigeria, Kenya, and Gambia, between 20 and 30% of the deaths of unweaned infants are due to malarial infection. The WHO also reports a recrudescence of venereal disease as a result of population movements or lack of health care facilities.
- The extraordinary and dramatic appearance of AIDS on the world health scene is another increasing source of concern. It is more of a pandemic than an epidemic disease, and one which is liable to become a significant demographic factor. In J. Caldwell's, P. Caldwell's, and P. Quiggin's (1989) views, the sociological and family structures in Africa are likely to make the population of this continent particularly vulnerable to this pandemic. Unofficial figures for some sub-Saharan African countries put the number of infected adults as high as 20%, and the figure is even higher in urban areas in Western and Central

Africa. According to the last WHO report, 10 to 12 million people worldwide have already been infected, and in the year 2000 the figure could reach 30 to 40 million. Heterosexuality is responsible for 90% of the infected people, including 10% for children infected by their mother. It is estimated that 8 to 10 million children will be infected by the year 2000, most of them in sub-Saharan Africa.

In fact, the virulence of the pandemic is related to a number of behavior patterns: these are not easily modified since they are rooted in the social fabric. It is in this context that J. Caldwell places the sexual and conjugal behavior of African populations. In regions with the highest incidence of AIDS, the death rate could double, which means that one out of two deaths would be attributable to AIDS. According to Heilig (1991) the progression of AIDS seems to be only a matter of time in industrialized countries, and it will have a significant effect on life expectancy, unless a cure and a vaccine were to slow down the pandemic. The same could be said for developing countries.

- The third cloud on the horizon in the Third World as far as health is concerned stems from these countries' economic difficulties. These are causing cutbacks in expenditure on health care, which already represents a far from adequate proportion of their total budget – rarely more than 5%.
- Fourthly, environmental damage may make progress toward better health an illusion, or partly cancel out its effects. The extension of deserts diminishes food supplies. Pollution and lack of water encourage the spread of diseases transmitted by this medium. Water also represents a danger in those regions of the Third World which are subject to flooding, particularly in tropical America and Asia (e.g., Bangladesh). Traditional barriers to infection often give way with migration to overpopulated and insalubrious cities, where health care facilities cannot keep up with population growth, especially given the economic restrictions.
- A fifth point which may be made is that many Third World countries which are well along the path to development are rapidly joining the health and mortality levels of the

industrialized countries. Thus, there is now a widening gap in terms of health and mortality between the industrialized countries and those countries of the Third World which are making economic progress on the one side, and, on the other side, those Third World countries that are not managing to move into the stage of demographic transition and development. This brings us to the idea that the differences between countries in terms of health and life expectancy are not tending to disappear.

Uncertainties about the rich countries

There are, finally, as many question marks about the demographic future of the industrialized countries as about that of the Third World. The industrialized countries have entered into what is termed the "post-transition phase", for which there has been no precedent. Neither governments nor experts have any direct experience of this phenomenon whose causes are rooted in society itself and could be eliminated only as the result of radical change.

As far as the demographic future of the developed countries is concerned, we are in the dark, as is evidenced by the vagueness of the term "post-transition phase". All the alternatives outside the well-trodden paths are open. The industrialized countries no longer have the certainty of the transition theory that has been guiding them until now. The only certainty is that of an inevitable aging of the population, and of having become magnets for the poor and jobless of the South. The projections concerning these countries are more a matter of judgment than genuine science.

Overview and Conclusions

Environmental concern, and the costs of dealing with it, is another factor widening the gap between industrialized countries and the Third World, as there is no doubt that population growth and its increasingly unbalanced distribution within different countries are playing a definitive role in the deterioration of the environment. Admittedly, true quantification of the relationship is subject to heated controversy, and many intervening factors are operating with population in a complex web, such as poverty, modern technologies aimed at increasing production to keep up with population growth and the need to catch up to living conditions in the industrialized countries, uneven income distribution, and so on. It might even be that these factors are more responsible for the environmental degradation than population.

It is likely that, at present, the Third World is more responsible for factors affecting the environment linked with population – deforestation and water shortage – whereas industrialized countries are more responsible for factors linked with industrialization. The relative impact could be approximately equal to a ratio of one to three. Nonetheless, with the process of population transition in the Third World, and some forms of "affluence" associated with it, the ratio could change drastically, and even reverse in the not too distant future.

We have commented on the fact that many of today's developing countries are or will be moving into the category of industrialized countries, and that there is a causal chain: demographic transition–development–industrialization–environmental problems. Never have we had so much evidence as we have today of the effect of demographic factors on development. If we take a close look at this, we see that it is those countries which are the quickest to reach the stage of demographic transition which have the best position on the international economic scene, and further ample evidence of this can be found in the contrasting examples of sub-Saharan Africa and some Asian countries, such as Pakistan, Bangladesh, and Cambodia. It can also be said that it is those countries which are in the midst of this period of demographic transition that have the advantage as regards the development of their economy, benefiting as they do from a steady influx of plentiful and cheap labor. The newly industrializing economies of Asia possess the three prerequisites for success, i.e., an emphasis on agriculture, a process of industrialization focused from the outset on exports, and a demographic policy designed to curb population growth.

A major issue is whether the countries that have completed their transition, or are getting closer to that stage, will have the technological and financial resources to remedy environmental damage. An estimate based on the United Nations' medium variant indicates that, by about the year 2025, the size of the population that will have completed the phase of demographic transition, and thus have achieved some form of industrialization, will be 6.8 billion, of which 1.4 billion will be in today's industrialized countries and 5.4 billion in today's developing countries. We can imagine what this means in terms of consumption of natural resources and efforts to prevent deterioration of the environment. What will the air we breathe and the water we drink be like if this population of about 6.8 billion human beings also manages to industrialize, as is hoped, and as the 1.2 billion inhabitants of today's "rich" countries are doing? Going from 1.2 billion to almost 6.8 billion "post-transition" inhabitants in the space of only 35 years will create enormous problems of adjustment. The source of these problems will not be the size of this population, but its propensity to damage or, on the contrary, to preserve the environment.

Is the theory of demographic transition to be revised, since fertility may turn downward sharply without real development, and therefore without strong industrialization? This is what China's case might suggest. However, China is an exception, and its rapid fertility decline was the result of a vigorous, unprecedented policy. Furthermore, China can be expected to reach an advanced stage of development and industrialization by the year 2025, or shortly after. It will be in a good position to recover during the next century the dominant position it occupied during the first millenium, thanks to its massive population.

One of the basic questions raised is whether those countries which will be going through the phase of demographic transition will have the ability to develop in a manner different from that of today's industrialized countries, that is to say, with less energy than is required for development by today's industrialized countries. The question is well discussed by Keyfitz (1992): "If a tight relation exists between energy use and income, and for unalterable physical reasons the correlation is as high as it is in the world today, then there is no way that the LDCs can attain the incomes of the developed countries ... ." In this connection, the rich countries' pleas for good behavior are likely to fall on deaf ears, as long as they themselves are not setting an example for "clean industrialization", or transmitting their "environment-cleaning" technologies, and, most importantly, the resources needed to apply them in developing countries.

There are indications that the United Nations' high-variant projections are more plausible than the medium-variant projections for the poorer countries of the Third World, at least as regards fertility. For sub-Saharan African or other very poor countries, the assumptions of both fertility and mortality decline on which the projections are based seem highly unrealistic. The health problems encountered by the poorer countries, such as the AIDS pandemic and the resurgence of malaria and (more recently) cholera, translate into the catastrophic health conditions prevailing in many of these countries, which could put a brake on population growth, as commented on by Caldwell (1991). Under the most pessimistic scenario, the decline in both fertility and mortality would slow down, delaying the end of the demographic transition. The medium-variant projection would only be accurate because of errors in both variables which would cancel one another out in the final rate of growth.

Whatever the case, these calculations show that there is something contradictory about a Third World policy which consists of accelerating the demographic transition by encouraging family planning, while taking no, or very few, steps to preserve the environment. The nearer a country draws to the end of the demographic transition, the more urgently action is required to protect its environment. The two policies – family planning and environmental protection – should be closely associated if the balance of the ecosystem is not to be severely disrupted, and the association must be a very long-term one. It may be said that to support family planning in the Third World without providing the necessary means of protecting the environment is to be guilty of disrupting this balance. In population and environmental policy alike, the rich countries are responsible to the developing ones, as they are to themselves, for transmitting the necessary technologies and resources for implementing them.

Clearly, it is first and foremost to the one billion inhabitants lagging behind as regards demographic transition and development that the information and educational campaigns on contraception should be directed in order to slow population growth over the long term. During the second half of the next century, the growth in world population is likely to come almost entirely from sub-Saharan Africa.

Finally, the hypothesis of a move toward a certain degree of demographic homogeneity, with the scenario of stationary populations in almost every case by about the end of the next century, as forecast by the projections, is unconvincing. As Paul Demeny (1989a, 1989b) writes, "the idea of a trend toward a stationary population may be justifiable from a normative standpoint, but it lacks support from the theoretical, empirical and historical standpoints." There is no objective necessity for a stationary population and there is no historical basis for it. Future demographic trends are not programmed, and a stationary population is not their automatic outcome. In fact, differences in fertility and mortality have never been as marked as they are today: the ratio of the fertility rate of Germany or Italy to that of many sub-Saharan countries is one to five. These differences have grown over time, instead of diminishing. Differential demography will continue to affect all sorts of relationships among countries.

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Conclusion

Peter E. de Jánosi

This selection of papers presented at the conference celebrating IIASA's first 20 years and reproduced in the preceding pages are a source of stimulating and productive ideas. They reflect the fact that the world of 1992 is vastly different from the one that existed when IIASA was founded two decades ago. Certainly the economic and political context in Central and Eastern Europe has changed dramatically, but there have also been notable developments in the West, as well as in the Third World. The changes in both the political and economic spheres have been dramatic. There is a growing awareness of environmental degradation at all levels – local, national, regional, and global. Our societies have become sensitized to the need to give greater attention to environmental matters, and to the linkages among environmental, economic, and social developments.

In addition, we have become more conscious of the fundamental and complex ways in which technology affects our lives – mostly positively, but alas frequently also with negative consequences. We are starting to regard technology not only as the sole solution to all of our problems, but at times also as the cause of further problems itself.

Many of these changes, especially those under the environmental rubric, have been subsumed under the title 'global change'. They are fundamental and well recognized. However, a few additional developments have begun to trouble the scientific community. One of these is the relationship between scientists and society. The public increasingly questions or doubts science and its findings. There is a curious love/hate relationship between our societies and scientists – the importance of which we must not underestimate or ignore.

Another development in the scientific community – a healthy one on the whole – is the growing recognition of the complex interrelationship among phenomena, interrelationships that are uncertain, dynamic, and non-linear. Experience has taught us that many of our most urgent problems cannot be dealt with in isolation, or from a single disciplinary perspective, and that simple linear analyses will not amount to much. Yet our body of knowledge and our teaching and research institutions are organized in ways that create hurdles for those wishing to analyze complex phenomena, and our analytical tools cannot adequately grapple with them. We at IIASA have stressed the need for interdisciplinary research, and can point with some pride to successful projects in which previous disciplinary perspectives failed.

These changes around us have already given, and will to an even greater extent in the future continue to give, a reconceptualized IIASA a special role. It is this role that is described in some detail in our Strategic Plan for the Nineties, entitled *Agenda for the Third Decade*. The *Agenda* is the culmination of an intensive year-long review by the Council of IIASA's strategic goals for the coming decade in the light of recent developments.

IIASA's strategic goal will be to continue to conduct international and interdisciplinary scientific studies to provide information and options addressing critical issues of global environmental, economic, and social change. Our intention is to make a contribution to the body of scientific literature, and also to say something relevant to policy makers and the public. Doing so will be a great challenge, for scientists rarely present their findings in ways accessible to policy makers, nor do they always address the sort of questions policy makers are confronted with.

IIASA's work in the 1990s will cluster around three broad interrelated themes:

1. *Global Environmental Change*. The primary goal will be to advance understanding of and develop the means to assess the interactions between human development and the environment. The environmental interdependence of nations has brought to

the fore a new appreciation of the significance of global environmental change. In general, attention will be given to the state of selected ecosystems of the atmosphere and climate, the ocean, aspects of the soil, and the complex interactions among them and with human activities.

Specific areas of concern will include the emission, transformation, and transport of toxic materials and pollution; changes in water resource availability and quality; the degradation of soils, biological resources, and ecosystems; and implications for managed agricultural ecosystems. These will be related to the principal human forces driving global environmental change, which include population growth, land use, development and industrialization, and energy production and utilization. The impacts of environmental change on many dimensions of society and the economy, such as industry, agriculture, land use, and living standards, will be assessed. Technological opportunities, regional strategies, and environmental policies that can potentially arrest environmental deterioration, and the economic and social implications of these strategies, will be examined with the aim of developing feasible options.

2. *Global Economic and Technological Transitions.* The world socioeconomic system is undergoing massive changes in the 1990s. This is related to the increasing economic interdependence of nations, rapid technological change, and the transitions of economic systems from central control to markets. Such processes are inextricably linked to the broad issues of global change. IIASA researchers will study these changes, transitions, and trends, explore quantitatively their implications, and assess policy options. Special attention will be given to issues arising from the transition from centrally planned economies to market economies, the integration of these economies into world markets, the impact of technological developments on all economies, and the complex relationships between the economy and the environment.
3. *Systems Methods for the Analysis of Global Issues.* Rigorous analysis and projection of these problem areas require a systems approach uniting mathematical modeling and other methods

that can deal with complexity, coupling of diverse processes, uncertainty, and non-linearity. IIASA will maintain a balanced research program in this area, with the emphasis on applying methodological expertise to practical problems in its central areas of concern.

In all of our work we intend to concentrate on interactions, that is, systems analytic aspects of these themes. IIASA's research program of interdisciplinary and international teams of researchers has been and will continue to be well received. The need for unbiased analyses of this nature has never been greater. Our connections to scientific communities and policy makers in many countries, coupled with our non-governmental status, place us in a favorable position to meet our goals.

One special area in which we hope IIASA can make a contribution is in building bridges between environmentalists and economists. There is something of a 'cold war' between these two groups, and while the consequences of this particular cold war will not lead to anything as devastating as a nuclear war, the inability of environmentalists and economists to find common ground creates serious hurdles. We intend to provide a home for research collaboration, an exchange of views, and neutral ground where perhaps a bridge or two will be erected. After all, IIASA succeeded in building East–West bridges when they were needed. Why can we not build economics–ecology bridges?

More generally, the fact that we are a functioning international, interdisciplinary institution may provide us with very special opportunities in the growing and widely dispersed global change research field. IIASA's governing Council is reviewing these possibilities, and, depending on the substantive and financial interests of governments, IIASA may turn out to have a special role in what some people refer to as the 'Global Change Enterprise', the collection of numerous inadequately connected efforts dealing with global change issues.

We are very much aware of the fact that many international scientific efforts consist of networks without a center. IIASA, on the other hand, is an institution with a staff that is not permanent, but nevertheless spends several years here on average. We too rely on many networks and collaborating institutions, but we are also able to contribute a core staff to that effort.

If IIASA is to realize this ambitious agenda, we at the Institute and our National Member Organizations must marshal the necessary intellectual and financial resources. The need for institutions to carry out systematic research on the broad range of global change issues is clearly recognized by many governments and, in a few cases, governments have translated this recognition into funding.

However, there is also reason for concern about the adequacy and management of these newly established national funds for global change research. National funding agencies are fully aware that many of the most important aspects of such research are truly international in scope, that they do not respect national borders, and that they cannot be dealt with by national actions alone. Unfortunately, this awareness is still not translated into adequate funding. The proportion of global change research resources that go to international research groups is far too small. This is not surprising since, by and large, the organizations that fund global change research receive their money from national taxpayers. These taxpayers are often reluctant to see their money sent outside their national borders, and for most national science-funding agencies the main objective is to strengthen domestic scientific efforts. International efforts, therefore, will always receive a lower priority.

Unfortunately this chauvinistic, though perfectly reasonable, practice will severely hamper international research efforts, of which IIASA is only a small part. International scientific efforts are necessary in order for international understanding and policies to be forged. In order to support international, interdisciplinary scientific efforts, a super-fund, an *international science foundation for global change research*, ought to be created. Each of the major countries with science foundations or equivalent agencies would make a contribution. The fund would then disburse its resources to the best international collaborative efforts. Only when international research networks and institutions have a well-defined funding body whose interest is international, not national, and whose agenda is dictated by international science policy concerns, not domestic concerns, will the global change enterprise flourish.

We at IIASA are relatively fortunate compared with many other international science efforts. We have sponsors from 15 rather like-minded countries who have assured us of their support. We are grateful to them for their effective articulation of IIASA's case in their own countries. However, we too would be further helped by the existence of an international science foundation.

The reconceptualized IIASA is now in a strong position to take a growing role within global change research efforts. Our plans for this decade are responsive to the needs of our societies, and we have the strong backing of our 15 sponsors to move forward. We look forward to playing a constructive role in addressing the many critical problems facing mankind.

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