FUELING EUROPE IN THE FUTURE
The Long-Term Energy Problem in the EC Countries: Alternative R&D Strategies

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FOREWORD

Basic technological systems such as the world energy system have come to join nature itself in forming the buttresses of man's activities. The interdependence this has led to in the contemporary world is nowhere better illustrated than it is by the evolution of the world energy system over the past ten years.

Countries that meet their energy needs largely through imports are particularly aware of this new kind of dependence. Clearly, the means for securing a sufficient measure of independence have to be found within such countries or within groups of such countries. However, an analysis of the problems that arise on the national level calls for an international perspective, which must also be long term to take account of the inertia of basic technological systems.

IIASA's Energy Systems Program Group set out to gain just such a perspective in its global energy study. The Institute sought to quantify the possibilities for providing enough energy for a rapidly growing world population obligated to promote economic development worldwide while using its energy resources wisely.

The narrow technological paths a cooperative world can take in order to achieve this goal have been pointed out in *Energy in A Finite World* (1981), the comprehensive report of the study by IIASA's Energy Systems Program Group. As well as the energy problem, *Energy in a Finite World* touches upon other truly global features, such as the effects of energy production and consumption on the climate and the environment, and the impacts of potential breakthroughs in science and technology. This information must eventually be input to institutionalized decision making – nonexistent at the global level – before it can actually be turned to use.

An opportunity to test the applicability of the global study arose with the Energy Systems Program Group's cooperation with the services of the European Communities in investigating the energy problem emerging in the EC countries and the R&D strategies they are seeking to develop in response. The three-year study, supported by two contracts from the Directorate General for Research, Science, and Education of the Commission of the European Communities, highlighted the complexities of international interdependence. It is documented in this report.

The report identifies some of the conflicts and differences that may arise between regional outlooks and a global perspective; between the balancing of demand and supply in a cooperating world, and the furthering of the objectives of a group of countries such as the EC in a competitive world. Some possibilities were explored of how to resolve these conflicts by way of alternative energy R&D strategies. These strategies were formulated as energy scenarios for the EC.

In the course of this study a gradual shift in focus occurred, as has happened with other truly novel analyses. The uncertainty about the directions of general economic development of the EC countries was found to match the uncertainty about the availability of reasonably priced energy on future world markets. The study prompted, but left open, the crucial question of the extent to which a forward strategy of enlarging the indigenous supply potential should help decouple the general economic development of the European Communities from the worsening international energy outlook.

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Acting Leader
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EXECUTIVE SUMMARY

Europe's present energy problem stems in the short term from relatively recent changes in oil prices on the world market. The European Community countries currently rely on oil, 80% of it imported, for around half of their entire energy needs. The extent of Europe's dependence on imported oil and its vulnerability to supply disruptions were sharply illustrated by the 1973 oil crisis and the fourfold price rises that followed. The energy problem of the coming decades will be much more than a matter of adjusting to higher prices, however: within thirty years the world's known reserves of conventional oil could be approaching exhaustion. The EC countries, poor in energy resources, must adjust their economies to a world energy system characterized by worldwide resource flows and increasing international interdependence. Since lead-times for the introduction of new energy technologies may range from thirty to fifty years, a detailed analysis of potential long-term global developments is needed to design R&D strategies for the EC countries that are consistent with the resource and technological constraints.

In 1979 the International Institute for Applied Systems Analysis entered into a contract with the Directorate General for Research, Science, and Education of the Commission of the European Communities to investigate the long-term energy problem emerging in the EC countries and the national research and development strategies they are seeking to develop in response. IIASA had recently concluded the first ever globally comprehensive study of the long-term world energy problem, in which researchers of the Institute's Energy Systems Program divided the world into seven regions of broadly similar economic and energy characteristics, and analyzed in detail their prospects for the fifty years to 2030, a period during which the world's population is expected to rise to eight billion. The study findings were guardedly optimistic – that the potential of known resources and technologies in hand or almost at hand will be sufficient to fuel a more prosperous world in 2030 that supports a population double that of 1975. Furthermore, by 2030 the world could be at the threshold of the critical and ultimately essential transition from an energy system based on depletable fossil fuels (coal, oil, and gas) to

one based on nondepletable sustainable resources (solar energy, advanced nuclear reactors, renewables, etc.). (The detailed results are presented in *Energy in a Finite World*, the two-volume report of the global study published in 1981 by Ballinger, and in an Executive Summary of the same title.)

In addition to the global study, the present investigation used an earlier study of the EC's long-term energy problem as a point of departure: in 1980 the EC published the final report of its own technical study, made by a working group from the EC, the International Energy Agency, and IIASA. (Commission of the European Communities (1980) *Crucial Choices for the Energy Transition*.) The study, which explored a range of conservation and supply options using trend extrapolations of demographic, economic, and technological parameters, was instructive, but had critical shortcomings: it did not take due account of the interdependence between energy prices, energy demand, and the rate of supply, and it neglected feedback effects on the EC countries caused by the responses of other world regions to the global energy problem.

IIASA's present investigation therefore represents an attempt to establish how the European energy system could be adapted by technological change to an optimistic assessment of future global conditions. The study explores the interaction between the energy system and the economy, adhering as closely as possible to a macroeconomic optimization principle that ties the economic value of energy to anticipated productivity levels of capital and labor.

The Approach to the Analysis and the Assumptions Made

The approach followed in the IIASA/EC study, as in IIASA's global study and in the EC's own *Crucial Choices* study, was one of scenario writing. Developing a scenario is neither to predict what will happen in the future nor to prescribe what should happen: it is simply a means of organizing the information available into comprehensive and internally consistent synopses of the possible course of events. The study concentrated on the physical and economic aspects of the energy problem, and the methods used were those of engineering and economics. Limiting the analysis and methods in this way necessarily mean incorporating the following implicit assumptions:

- The future will be for the most part "business as usual". There will be no catastrophic wars; nor shall the energy problem be solved by technological panaceas.
- The world will be blessed with a high degree of international cooperation. Thus the results indicate *what can be done* with the world's endowment of energy resources, manpower, capital, and knowhow. In particular, the study assumes that there will be a functioning world trade in coal, oil, and gas, allowing resources to flow from the resource-rich to the resource-poor countries, and that there will be no new cartels to fix energy price levels substantially above the cost price levels used for all nonoil trade in the scenarios. Developments since 1975 indicate that this is over-optimistic, as countries have come to limit their oil and gas production in view of their own long-term national needs, and other energy prices have closely followed oil prices.
- Those social and political dimensions of the energy problem not explicitly

included in the analysis will not severely curtail the development of energy supplies during the next fifty years. The constraints taken into account in the study were physical (such as the heating values of different coal deposits), technical (such as the efficiency of electricity plants), and structural (such as the limitations on the rate at which one energy source can be substituted for another). It must always be borne in mind when drawing conclusions from the results that social and political constraints, for example on nuclear energy growth, have been deliberately disregarded in this analysis.

- Inflationary effects are negligible. The analysis of the competitive economics is carried out in terms of constant US 1975 dollars; thus monetary aspects of the energy problem, particularly those associated with eroding creditworthiness, are not taken into account.

To this list should be added the following two assumptions, which explicitly underlie the data used in the scenarios.

- A vigorous exploration for new energy resources in Europe is assumed.
- Economic growth rates are assumed to be moderate and to decline steadily over time, though remaining positive.

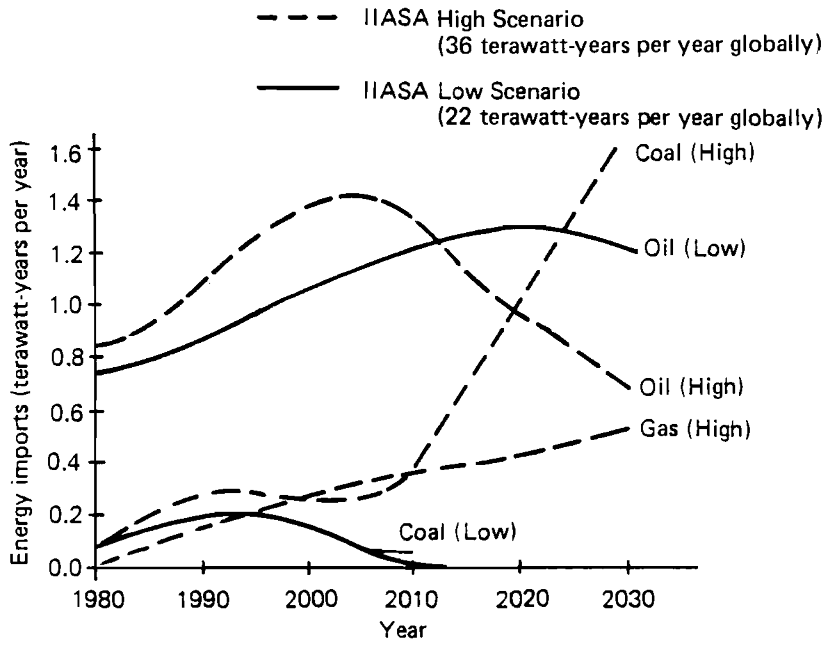
By taking into account the quantitative findings of the global scenarios, translated to the regional level of the EC, with these assumptions, IIASA developed a set of macroeconomically consistent energy supply scenarios for the EC countries based on the optimal allocation of capital, labor, and energy.

The Method of the Analysis and the Findings

Adaptations to the rising energy prices of the past decade are sometimes termed conservation, sometimes efficiency improvements, and sometimes productivity increases. Each of these involves reducing the amount of energy needed to perform some service by replacing it with something else. In some cases energy can effectively be replaced by capital (e.g. by investing in home insulation); in others by labor (e.g. in tuning an engine to reduce its fuel consumption); in still others it may be saved simply by ingenuity or knowhow (e.g. by designing more efficient jet engines or new processes in steelmaking, or even just by making more carefully planned shopping trips). Thus rearrangements of resources of capital, labor, and knowhow can conserve energy, and appropriate investment of these resources – in education, research and development, capital equipment, exploratory drilling – can increase the stock of resources that can be put to use.

Where the present IIASA analysis differs from previous studies of the EC's energy options is in treating energy as a factor of production, just as capital and labor. The underlying idea in the IIASA/EC scenarios was to postulate equilibrium conditions for the substitution of capital and labor for energy: that is, to arrive at the optimal allocation of the three resources. If the marginal productivity of capital and labor is high, then it is costly to substitute either of these for energy. This point has important implications, since previously proposed technically oriented energy strategies for the EC countries were found to imply a degree of energy conservation and substitution away from oil that does not appear economically justified at the oil price levels characteristic of global supply opportunities.

The IIASA/EC study found previous investigations of the European energy future to be over-optimistic with regard to economic growth, as well as energy import opportunities and conservation potential. In the new IIASA/EC scenarios a substantially lower rate of economic growth is projected.



Energy imports of IIASA Region III (Western Europe and Japan) in the two scenarios of the IIASA global energy study *Energy in a Finite World*. The reduced dependence on oil imports in the high scenario is replaced by an increased dependence on coal and natural gas imports. In the low economic growth scenario oil imports grow more slowly, but the dependence on oil imports extends well into the next century with no possibility of building alternative fossil systems quickly.

The study used computer models to simulate energy demand and supply, to balance the two over the five decades of the study period, and to examine the long-term macroeconomic implications of alternative energy supply scenarios. Future energy demand was projected by extrapolating demographic, economic, and technical parameters. This involved making assumptions about the economic growth rates of the various sectors of the EC economy, broken down in the study into the production of goods, freight transportation, passenger transportation, households, and the service sector, and then further subdivided. Projections of energy efficiencies, growth rates, shifts between sectors, and energy-related details of lifestyles were then made: extent and means of travel, heating requirements, and so on.

The next step in the common methodology for both the IIASA global study and the *Crucial Choices* study was to explore the possibilities for providing the required amount of final energy using available resources and technologies, the central objective being to minimize the overall cost of the primary energy forms (e.g. coal, oil, gas, uranium).

The IIASA global study found a transition in the allocation of energy exports from the resource-rich developing countries in Latin America, northern Africa, and the Middle East at about the turn of the century. The rest of the developing world (most of Africa and southern and south-east Asia) switches from being a net exporter of energy to being a net importer. North America, whose oil imports are assumed to decline to zero by this time, is thus replaced by the developing countries in competition for oil with the European countries and Japan. Over the next few decades, the global scenarios envisage a shift away from the present high imports of oil into Western Europe from the OPEC countries to high imports of gas and later coal from the Soviet Union, Eastern Europe, and North America.

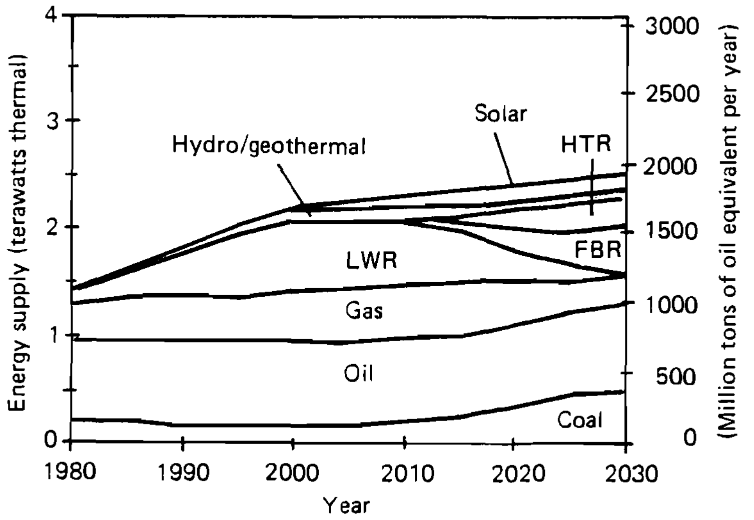
One formidable problem in the EC countries will be the provision of liquid fuels for transportation and chemical feedstocks; crude-oil-based products alone will be insufficient to meet the projected demand. For this reason coal liquefaction to produce synthetic fuels was included in the study, on a world scale from the year 2000. Renewable resources, as a result of the long lead-times involved, make a relatively small, but nonetheless important, contribution by 2030.

For the next half century, fossil fuels will continue to dominate the world's energy supply. Global consumption of both gas and oil will actually continue to increase over the next fifty years. The two resources will become progressively costlier to produce, however, as deep off-shore deposits of oil and deep gas formations are exploited. Furthermore, gas and oil will need to be complemented with "dirtier" hydrocarbons such as oil shales and tar sands that are also less accessible and more expensive to extract.

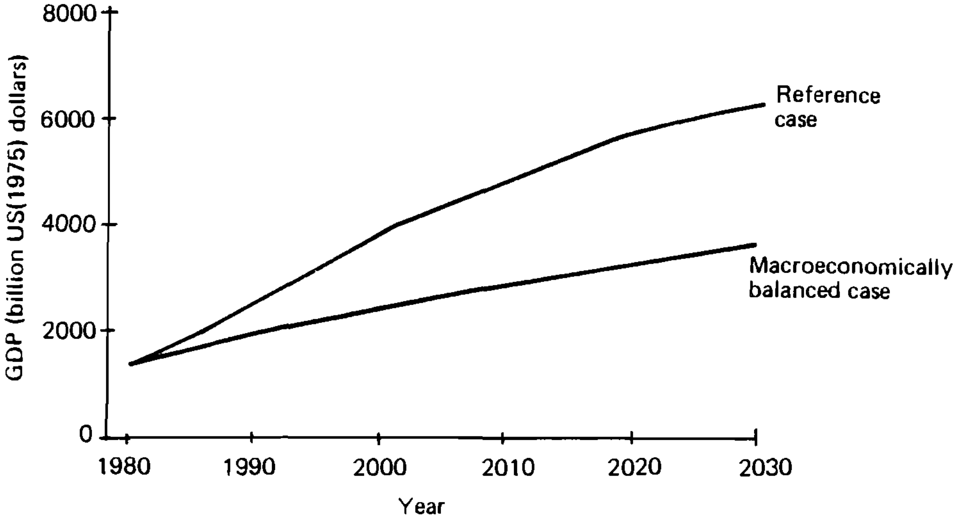
The macroeconomic growth model MACRO was used to cross-check the impact of each energy supply strategy on the economic environment in the EC. The macroeconomic demand and supply of capital, labor, and energy as a third factor of production were balanced and the level of economic growth determined. This cross-check revealed serious inconsistencies in the *Crucial Choices* scenarios between the evolution of energy demand and the equilibrium energy cost. That is, the energy conservation effects assumed in the study are inconsistent with the energy cost level calculated to correspond to the expansion in demand.

These energy cost/energy utility considerations lead to the central question of the extent to which the energy problem might obstruct an otherwise feasible economic evolution in the EC, and the corollary question of whether the energy sector should be isolated from the rest of the economy and stabilized through transfer payments. There are clearly conflicting objectives involved in restructuring the energy system while coping at the same time with soaring import costs and declining general economic growth.

A modification to the scenario writing procedure was introduced to produce two new IIASA/EC scenarios. In the new approach, labor productivity and labor force participation rates are determined exogenously and serve as inputs to the models, which then calculate economic growth projections internally by clearing markets for capital, labor, and energy. In this way a macroeconomically consistent demand scenario was developed and used to investigate the trade-off between increased domestic investment and increased energy imports.



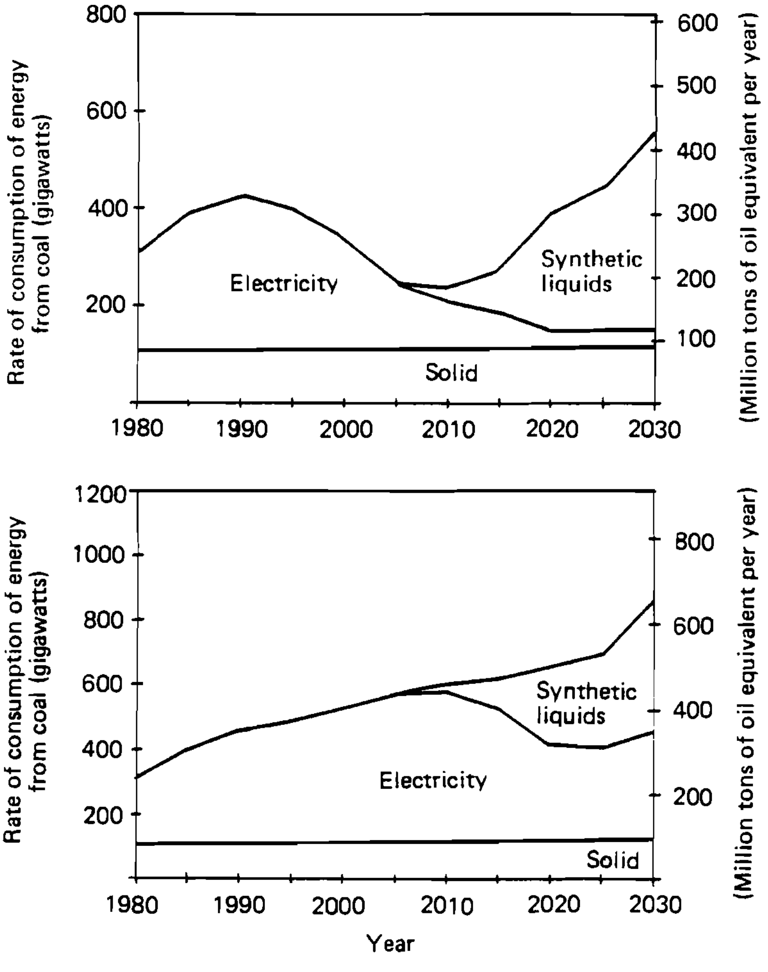
The EC Acceptable Dependence energy supply case from the *Crucial Choices* study: primary energy inputs calculated in 1980 for the European Communities on the basis of optimistic assumptions about economic performance, technological advance, and extended energy trade. HTR, high temperature reactor; FBR, fast breeder reactor; LWR, light water reactor. This reference scenario balances the roles of fossil fuels and nuclear energy and rests on a rather strong energy conservation trend.



Evolution of the net GDP of the EC countries in the 1980 reference case and the newly designed balanced macroeconomic growth case for the EC. For this latter case a "nuclear" and a "coal" version were compared.

Two alternative future energy supply paths were then analyzed to define the range of technological choices open to the EC countries in a medium- to long-term future of low economic growth. One is characterized by the assumption of favorable capital costs for nuclear energy (the Nuclear Scenario); the second has rather higher costs for nuclear energy, thus favoring coal technologies (the Coal Scenario). The GDP growth rates in the two scenarios are almost identical, declining from an average of 2.2% per year (1985–2000) to 1.1% (2015–2030), but resources are found to be allocated quite differently. Energy import costs roughly double between 1980 and 2030, with a dependence of about 28% on imports in the Nuclear Scenario. The figure in the Coal Scenario is about 39%.

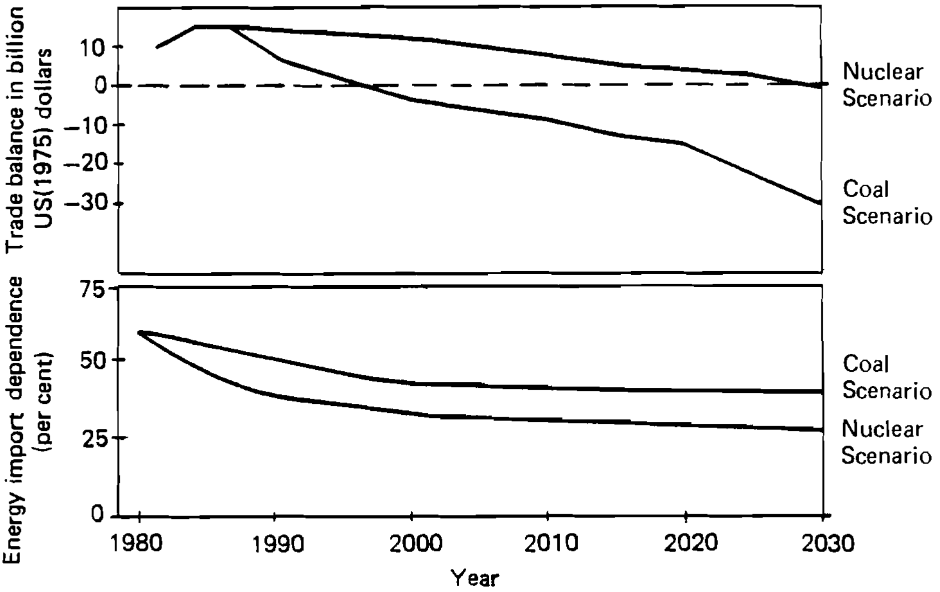
In the Nuclear Scenario coal consumption drops off substantially by 2000–2010. Coal in effect fills the electricity generating gap until there is sufficient nuclear capacity available to meet demand. In the long term the role of coal is as a raw material for liquefaction to produce synfuels. In the Coal Scenario coal production was increased to permit a more limited introduction of nuclear power, and in particular to delay the deployment of advanced nuclear reactors. The introduction of advanced nuclear reactors is thus delayed beyond 2030. The consumption of uranium is actually higher in the Coal Scenario owing to the later introduction of advanced reactors and the consequent greater utilization of



Uses of coal in scenarios favoring (a) nuclear and (b) coal technologies respectively. The liquid fuel market is hardly affected by this variation.

light water reactors. In fact, the world's uranium resources, which are in energy terms the rough equivalent of global oil reserves, are almost exhausted in the Coal Scenario, raising the possibility of future energy crises arising from uranium shortages.

In both cases the energy sector charges against the rest of the economy. In the Nuclear Scenario the economy is more capital intensive owing to the build-up of an advanced nuclear infrastructure. Reactors consuming enriched uranium are projected to be replaced with advanced reactors well within the fifty-year study period. The fact that the earth's resources of uranium are almost exhausted in this scenario emphasizes the importance of high temperature reactors, which can also use thorium as an energy source.



The different effects on the energy import dependence and the trade balance in the macroeconomically balanced Coal and Nuclear Scenarios.

The two responses, the Coal Scenario and the Nuclear Scenario, impede economic growth fairly equally on the basis of the costs assumed. It makes little difference whether the same amount of energy is provided from indigenous sources or by increasing imports and running trade deficits.

An assessment of the two scenarios in terms of two tentative EC policy goals of limiting import dependence and the dependence on any single primary energy source shows that in 2030 coal provides 35% of primary energy supplied in the Coal Scenario and nuclear energy 34% of primary energy in the Nuclear Scenario. This indicates the importance of advanced reactors in replacing energy imports if energy self-sufficiency becomes a primary goal.

The two scenarios thus chart the extremes between which the path of future energy development can be chosen. The fact that this fairly narrow choice is based on an optimistic view of the availability of primary energy, assuming free market access to world energy resources and consistent world energy trade, highlights the technological flexibility the EC countries must develop to be able to respond to changes on international energy markets. The choice of emphasis between coal and nuclear energy is a critical one, requiring decisions and adjustments well in advance of implementation. There are other alternatives that must be kept in view, such as the liquefaction of natural gas and its transport over large distances. Still further options, such as nuclear fusion and centralized solar energy, are beyond the time horizon of the study. The scenarios that have been developed thus map an area of maneuverability for energy R&D strategies: they link energy policy goals and likely technological achievements with broad European and world evolutions, and, in view of the optimistic "stable globe" hypothesis, they represent best-case strategies for Europe. General economic growth, the dependence on oil imports, and the nuclear power buildup are all directly linked; alternative energy sources will not provide much more flexibility before 2000. This means that any developments that further restrict maneuverability will necessitate greater improvements in productivity, further exploitation of resources, a higher import dependence, or lower economic and social aspirations.

The macroeconomic model that determines the most productive use of capital, labor, and energy indicates that conservation may not be a reasonable way of stabilizing the international balance of demand and supply: in all the scenarios it was found that saving one unit of energy reduced the GDP by about five times the economic value of the conserved energy unit. That is, reducing the energy input into the EC economy by substituting highly productive capital or labor reduces the GDP by far more than the value of the energy conserved.

Conclusions

The goal of the study was to investigate the implications of the findings of IIASA's global energy study for the countries of the European Communities. No optimal energy strategy has been identified. Indeed, the European energy problem cannot be solved by considering the energy sector in isolation and seeking to design technical or technoeconomic solutions. The energy problem must be seen to be part of a more comprehensive challenge facing Europe that demands a flexibility of response in technology, in economic development, in international cooperation, and in lifestyle adaptations, to temper regional interests in order to bring global energy demand and supply into balance.

If the EC countries want to achieve a measure of independence from the increasingly uncertain development of international energy relations, a policy of building up internal supply capacity should be investigated, even at production cost levels well above current international energy prices. This policy could be tested using the scenarios to determine the sensitivity of the EC countries to fluctuations in global conditions governing its access to external energy resources. Supplies could be supplemented by energy imports that in a case of classical resource shortage would not automatically be in demand in other industrialized regions. Uranium and low quality coal might be suitable, but this would presuppose independent European technological programs that differ from R&D programs for resource exploitation in the rest of the developed world.

Traditional economic cost-minimizing principles will never, against a background of rising energy costs, stimulate the technological innovation needed to take Europe up to the energy transition. Furthermore, the less rewarding the basis on which the old infrastructure operates, the slower is the rate at which a new and even less rewarding energy system can be introduced. This means that the transition to a sustainable energy system is likely to become more difficult the longer it is postponed, in which case time also becomes limited and precious.

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ABSTRACT

Under a contract from the Commission of the European Communities, the linkage between the energy problem and the national R&D strategies of the EC countries was investigated in the light of the results of IIASA's long-term global energy study, documented in Energy in a Finite World *(1981). By considering what may be feasible over the next fifty years in other industrialized world regions, substantial discordance is revealed between the desires of the EC countries for economic growth, energy conservation, and energy imports, and the need for a global balance between energy demand and supply.*

A way of gradually harmonizing regional energy strategies with the constraints on resources and technologies identified in the IIASA global scenarios has been developed. The two alternative scenarios developed are based on a macroeconomically optimal allocation of capital, manpower, and energy. Given the limited oil imports of the EC in IIASA's global projections, two limiting scenarios are presented to indicate the narrow technological choice in a medium- to long-term future for the EC countries of low economic growth. The two scenarios have either coal or nuclear power as the favored energy option, supplemented by the other source.

1 INTRODUCTION

The purpose of the present study was to translate the results of IIASA's globally comprehensive investigation of the long-term energy problem to an intermediate level – the level of the European Communities. Globally compatible energy strategies were compared with potential energy strategies reflecting the preferences of the member countries of the European Communities. Alternative strategies can be devised when such comparisons reveal significant discrepancies between a bottom-up approach (Western Europe's view of the world) and a top-down approach (the world's view of Western Europe). Developing an alternative European energy strategy capable of harmonizing regional and global outlooks allows us to assess the impacts of external constraints and limitations on the evolution of European energy technologies and to design resilient energy R&D strategies. In more general terms: once translations from the global level to the EC level are consistently quantified, the prospects for Europe of coping with the energy problem in a competitive world context can be assessed against a neutral global yardstick.

We note here that the methodology developed and applied under this contract could also be used to interlink the aggregate intermediate level of the EC and each of its nine (at the time of this study) member countries. Investigations of this kind were not undertaken under this contract, however.

The report summarizes the collaborative work of the services of the European Commission and the Energy Systems Program of IIASA in several blocks. Each block comprises a problem-oriented investigation and the direct results obtained within the confines of the question that guided each particular investigation. Figure 1.1 lists these blocks arranged in the order of the work. The evolution of the scenarios, their relative divergence, and the steps taken to harmonize the EC outlook with the IIASA global scenarios used as a yardstick are thus self-evident from the figure; in fact, Figure 1.1 represents a learning process.

The short-term European energy problem was caused by the recent dramatic changes in world energy markets. Reactions to this imported problem clearly have to concentrate first on appropriate technical adjustments within the energy system; here improved energy efficiencies, energy conservation, and the utilization of alternative indigenous and extraneous supplies are foremost.

At a later stage of the investigation it became obvious that the long-term European energy problem will have a distinct home-made aspect. In time, Europe's ability to adapt the structure of the productive and consumptive parts of its economy to a new energy supply situation will substantially influence the nature of its energy problem. Questions of labor productivity, savings rates and balance of payments problems, and substitution between capital, labor, and energy increasingly influence energy scenarios. Ultimately the EC study and the IIASA/EC study together produced a set of nine scenarios. These vary basically in their projections of energy-consuming and energy-producing technologies, and in some parameters describing general economic evolution.

All the scenarios are biased with regard to one principal assumption: smooth evolution. The various data inputs, whether technical or economic parameters, and the continuation of present decision criteria (e.g. cost minimization, limitations on import dependence, absence of new cartels) assume a stable and cooperating world. The possibility of discontinuities, in the form of changes in certain constraints or decision criteria within the time horizon of the study, is excluded. The internal stability of the model calculations is largely a consequence of this basic assumption. For this reason alone the scenarios could not be taken as predictions of the future. Furthermore, none of the scenarios implies a balanced set of economic and technical assumptions. Instead of covering likely evolutions, each scenario tries to take one single substrategy to its credible limits in order to explore its problem solving potential. Thus, to a limited extent, the interplay of the energy problem with other evolutions can be traced. Throughout the study, in fact, the energy problem has always been understood as part of a more comprehensive challenge to Europe, requiring a flexible response in the fields of technology, economic development, lifestyle adaptation, and also international relations. Certain aspects of this challenge are gauged in this particular methodological approach when a balance between demand and supply of energy has to be achieved in each scenario. Thus, all the scenarios taken together map an

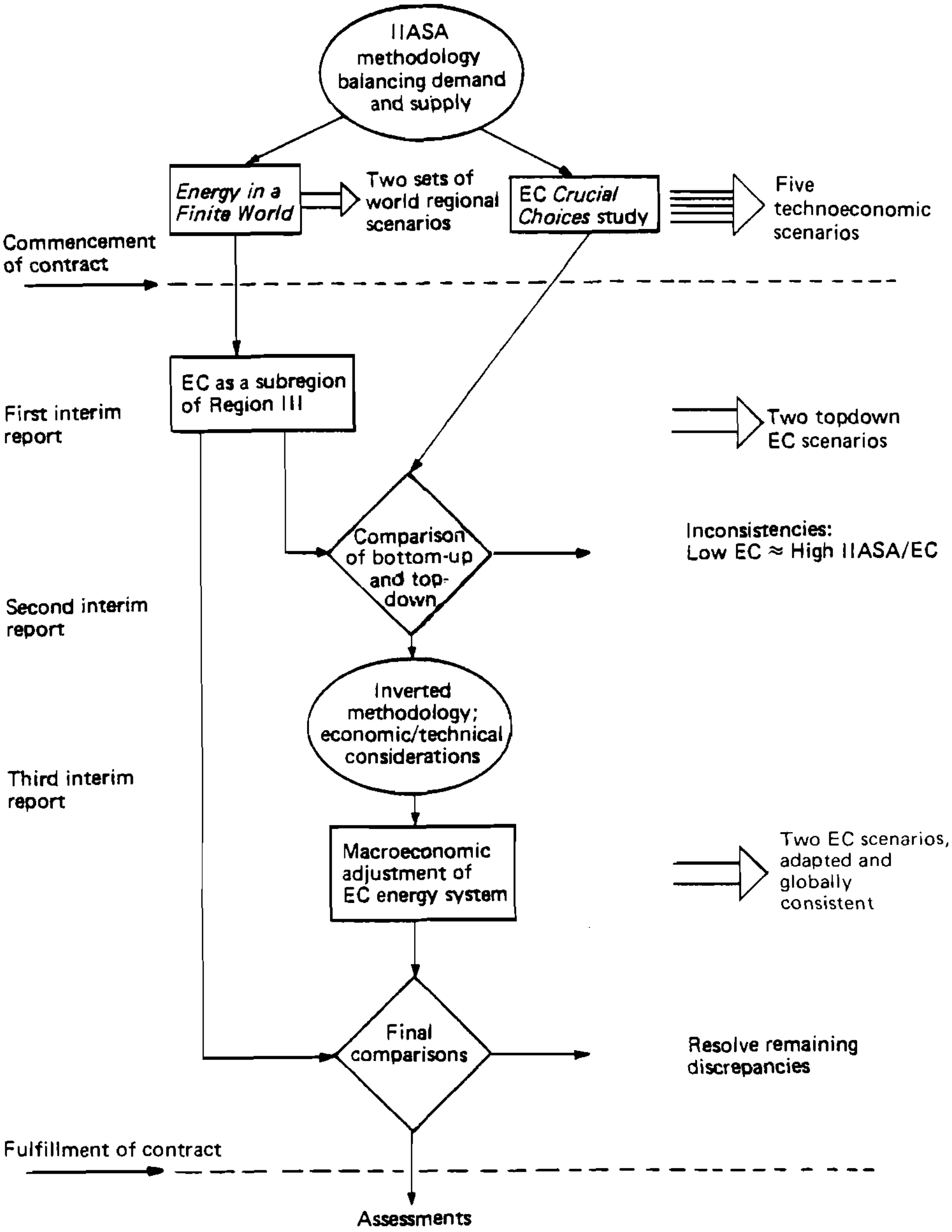

FIGURE 1.1 Schematic diagram of the IIASA/EC Study.

area of future maneuverability. It is on this basis that energy R&D strategies must be assessed. Though limited by the assumption of a stable and cooperating world, the set of scenarios interlinks particular energy R&D goals and eventual technological achievements with a broader set of European and world evolutions.

Should the goals be set too low or should the actual deployment of energy technologies fall short of the levels assumed in the scenarios, the area of maneuverability defined by the variations in the set of assumptions would necessarily become even smaller. The problem would then become one of further improving capital and labor productivity, of exploiting resources so far conserved, of political compensation for import dependence, and of lowering economic and social aspirations.

In line with the main objective of the study – to translate the findings of IIASA's global energy analysis to the level of the European Communities – no optimal energy strategy for Europe has been identified. In view of the crucial hypothesis of a stable and cooperating global system, the scenarios in this report essentially outline best-case energy strategies for Europe. We hope that our study will form a cornerstone for further work that would fix strategic R&D goals for energy, taking due account of the uncertainties of the real world – competing and potentially unstable.

2 GLOBAL ENERGY PERSPECTIVES AND THE EC OUTLOOK

The point of departure for the study was the two sets of future scenarios that evolved from two separate analytical efforts. The Energy Systems Program Group of IIASA completed in 1979 a high and a low global scenario, encompassing a range of possible evolutions of the global balance of energy demand and supply. The IIASA scenarios assess realistic possibilities for developing the energy systems of seven distinct and globally comprehensive world regions by referring to an exceptionally favorable state of world affairs – stable and cooperating by definition – over the next fifty years (Häfele 1981).

At the same time, a working group from the EC, the International Energy Agency (IEA), and IIASA finished the first-ever quantification of the long-term energy future of the EC. The EC results were formulated as five alternative scenarios in *Crucial Choices for the Energy Transition* (Commission of the European Communities 1980). The two sets of scenarios use the same types of formalized computer models and draw partly on identical or related data bases, but they focus on different aspects of the energy problem.

The quantitative results, and more so the conclusions of both sets of scenarios, do not fully coincide. Rather, conflicting strategies can be elicited from the two sets of scenarios. This is not unreasonable, since the objectives of a national or in our case an EC energy strategy do not necessarily conform with the need of an interlinked global system for the consistent evolution of its constituent parts.

2.1 The Methodological Approach

Before the main results of both studies are summarized, a brief outline of the common methodology is given. It enables us to specify which objectives and which activities eventually shape a particular energy strategy. The methodology also to some extent determines future perspectives: it reduces the many aspects of potential evolutions to those aspects that can be quantified using today's comprehensive national and international statistical services.

Figure 2.1 specifies the elements of a set of computer models capable of producing a balance between demand and supply of energy over several decades. The computer models need quantitative inputs. Some of these inputs relate to future evolutions in energy-related fields. Depending on the sequence of model operations, these inputs either act as driving variables representing prescribed objectives or assume the function of strategic elements contributing to the solution of the energy problem.

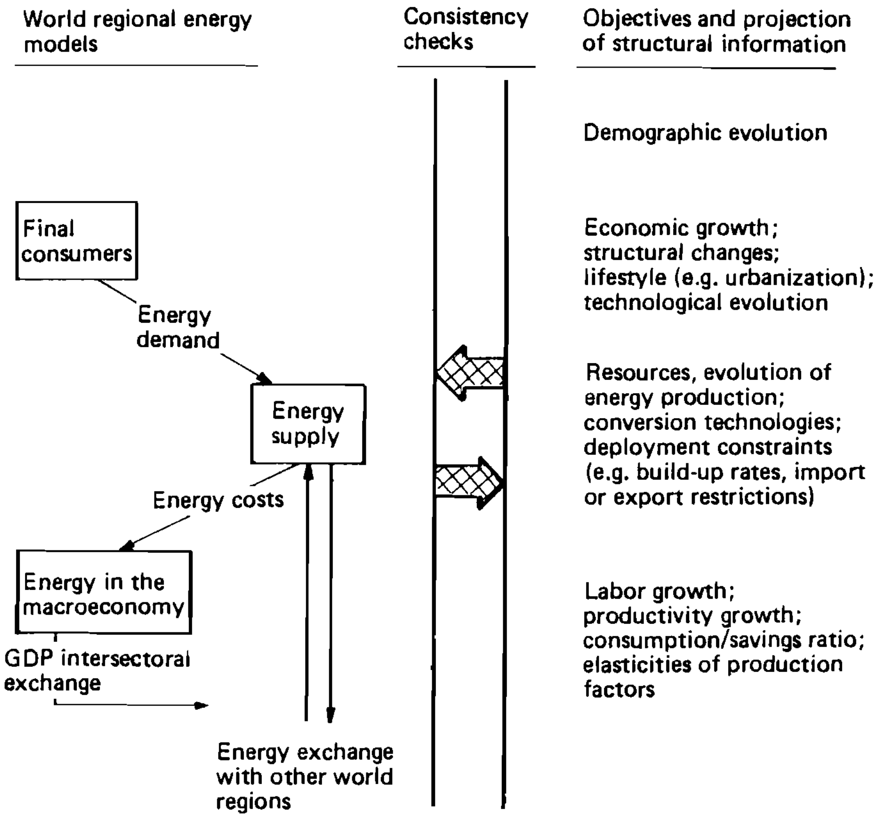

FIGURE 2.1 Model elements for generating scenarios of the European energy future.

Future economic growth assumed the role of a normative (prescribed) driving force in both the global and the EC analyses. Its evolution as presently foreseen, together with projections of demographic growth and technical changes in lifestyles (expressed as structural changes between the main sectors of the economy and predicted changes in the energy intensity of each sector), determine the demand for final energy. The projected lifestyle changes imply a broad spectrum of policy actions aimed at energy conservation. Whether these actions will be economically justified by energy price increases, or whether their side effects will accumulate to present insurmountable obstacles to conservation are, and will remain, open questions. At this point, informed judgment is the only means of confining the set of technical lifestyle adjustments within a reasonable overall evolution.

Such judgment is aided, however, by comparing the effects of different lifestyle changes and consumer technologies on the spectrum and time evolution of final energy forms.

Alternative demand scenarios were explored at different stages of both analyses and gradually converged to "middle-of-the-road" paths. It is important to note that such exercises quickly show diminishing returns for energy conservation that results from extreme lifestyle prescriptions.

The second distinct step in the methodology of Figure 2.1 is to consider the alternatives for providing the amount of final energy demanded using available resources and production and conversion technologies. The overall minimum cost for the total energy supply over the fifty years considered is the central objective in the allocation of primary energy forms. The macroeconomic rationale is to impose the least possible burden on the economy as a whole. Energy trade with other world regions enriches the potential supply patterns.

To arrive at a global supply balance, the IIASA approach introduces self-sufficiency objectives for some world regions and a maximum earnings strategy for oil exports from the Middle East and northern Africa. These strategy provisos necessarily lead to cost differentials for regional energy availability. (This consistency problem disappears for quantitative reasons in most of the IIASA world regions.) Again, judgment is needed to weigh the benefits of regional independence against the concomitant elevated internal costs.

Fundamentally different conditions obtain for the EC, however. The extremely unfavorable position with regard to fossil resources suggests introducing into the supply allocation procedure limits to the availability of primary energy forms; at the same time, minimizing vulnerability suggests setting upper bounds for overall import dependence. The narrow resource base, together with supply policy constraints, largely determines the supply allocation of the EC. Energy costs have only a marginal influence in this stage of the balancing procedure for the EC.

A crucial feedback between the output of the resource allocation model and the inputs to the demand model of the first step results from an assessment of how the resource situation changes over the course of time.

Figure 2.2 summarizes the main judgmental interventions that shaped the process of scenario writing for the long-term global evolution. This figure specifies the formalized models and the particular consistency checks behind the two scenarios for IIASA's world regions: the global High Scenario and the global Low Scenario. Both these comprise distinct scenarios for each of the seven world regions that were considered. Figure 2.2 is thus a particular implementation of the methodology shown in Figure 2.1. The outstanding problem of this global scenario writing process was the interplay between the depletion of fossil fuel resources and overall global economic development. Three phases of "reactions" to the quantitative responses of the models led to corrections to initially fixed objectives or to estimates of evolutionary trends. Firstly, unconventional fossil as well as renewable resources and, secondly, enhanced energy conservation were introduced in consecutive feedback loops. Eventually, substantially reduced economic growth had to be considered in view of the aggregate estimates of technologically accessible energy resources.

The objective in balancing energy demand and supply in the five EC scenarios was different from that in the two IIASA global scenarios. Whereas the IIASA study tried to determine the possible overall evolution of the global energy system, the EC study focused on technological responses of the EC to an energy problem that was assumed to remain

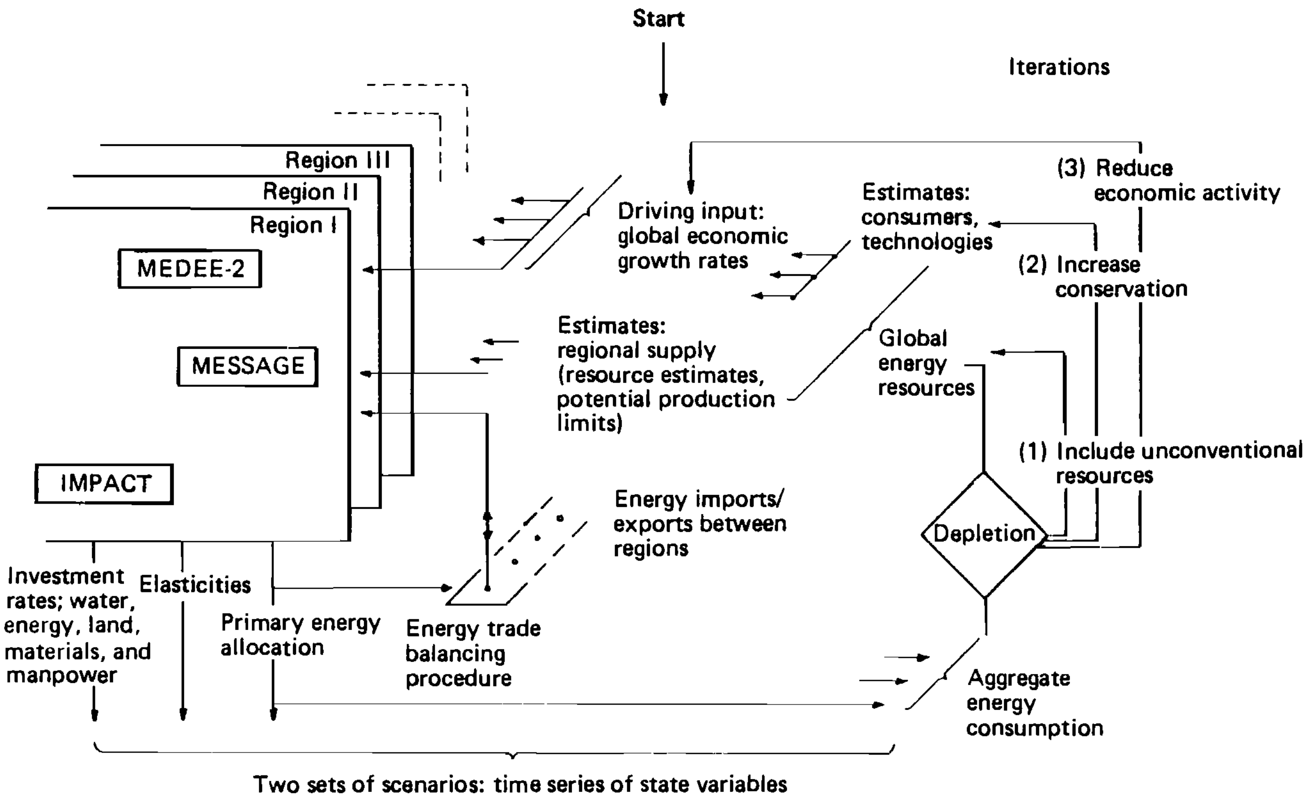

FIGURE 2.2 The process of scenario writing: the IIASA global High and Low Scenarios.

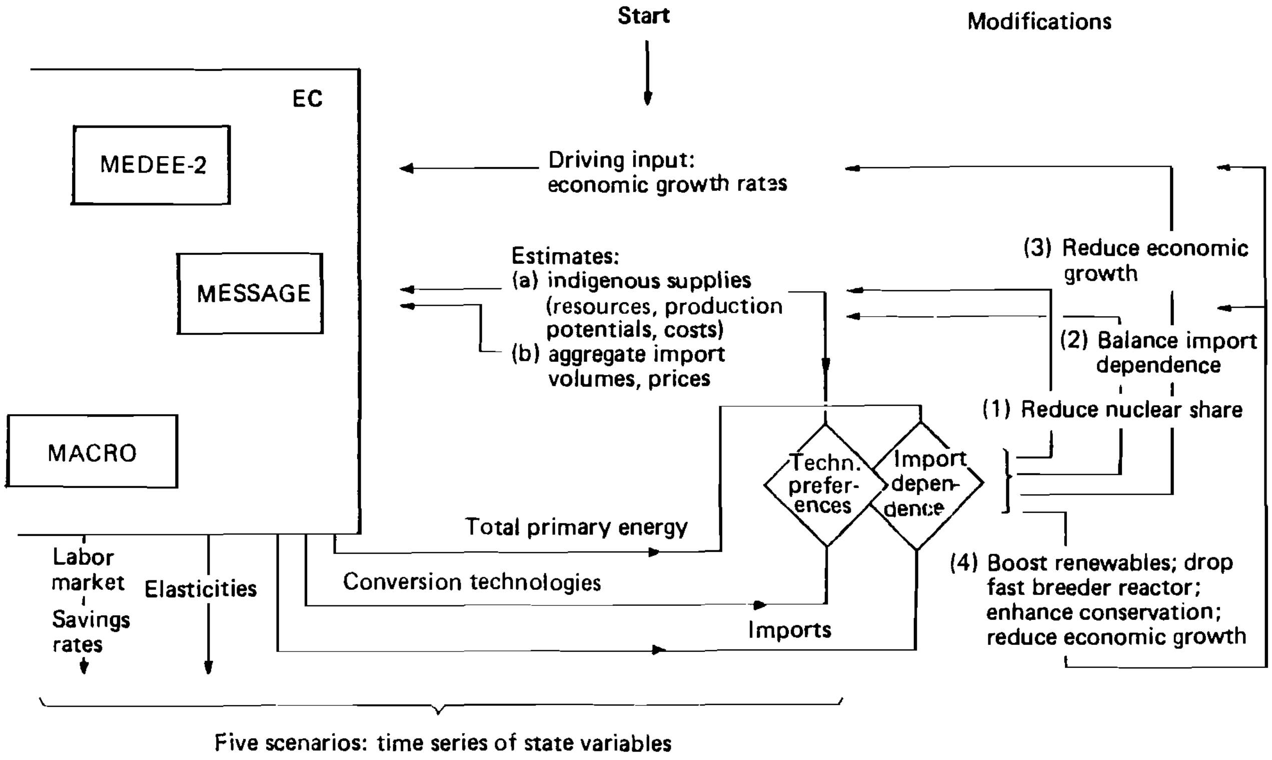

FIGURE 2.3 The process of scenario writing: EC *Crucial Choices* Cases I, II, IIa, III, and IV.

within the energy sector. The methodology of Figure 2.1 is flexible enough to cover these different strategic emphases. However, the implementation of the scenario writing process in the *Crucial Choices* study (Commission of the European Communities 1980) led to different decision patterns. Figure 2.3 records the conflicting policy variables "technological preference" and "energy import dependence limit" in the feedback loop connecting the output of the energy supply model and the inputs of the energy demand model, as well as the normative constraints to the supply model. These latter constraints reflect the estimated conditions on global energy markets, to the extent that they affect the EC.

A comparison of Figures 2.2 and 2.3 reveals that the conceptual differences in the studies of the global and the EC energy problem were mainly confined to these judgmental adjustments in the respective feedback loops. The twofold concerns dominating the EC scenario writing process partly explain why five EC scenarios were developed but only two scenarios in IIASA's study of the global evolution.

The common methodology of both studies (see Figure 2.1) contains a third stage. It is designed to assess the impacts of the energy sector operations, balanced in the preceding two stages of demand and supply modeling, in terms of macroeconomic relationships. In principle, such impacts allow the introduction of alternative feedback loops connecting the macroeconomic level and the microeconomic level of either energy consumers or energy suppliers. Such feedbacks have not been incorporated to yield alternative scenarios, either in the global analysis by IIASA or in the *Crucial Choices* study. Instead, changes in macroeconomic parameters have been monitored for both sets of scenarios. They can be interpreted as provisos to be fulfilled by institutional and political adjustments to the perceived energy problem.

For the global study, the changes in the industrial structure of each world region as a consequence of constructing the energy supply system were an important concern. Consequently, investment requirements, both direct and indirect, and manpower and materials balances were calculated. These provide a basis for judging the plausibility of the driving assumptions on economic growth and structural change that influence the energy demand projections. However, no modifications to the scenario writing process were made on the basis of the significant macroeconomic changes identified.

In contrast to the global study, considerations of energy investments in relation to total capital investment rates and import bills for energy were in the forefront of this monitoring phase of the EC study. This is a direct consequence of the high energy import dependence and the need for an early and quick modification of the existing EC energy supply system. Again, macroeconomic evolutions and changes of present macrocharacteristics were monitored for the five EC scenarios that resulted from the procedures shown in Figure 2.3, but no iterative modification of the scenarios was made in the EC study.

After this brief description of the general approach and the specific objectives of the two independent analytical efforts, it should be pointed out that the differing evolutions of the energy systems in the seven scenarios that existed at the start of this contract study must be seen as being the answers to different questions. The quantitative details are summarized briefly in sections 2.2 and 2.3.

2.2 The Potential Evolution of Industrialized Countries with Scarce Energy Resources in the IIASA Global Scenarios

The nine countries of the EC are included in IIASA's World Region III, which is a conglomeration of highly developed industrialized countries, basically the OECD group without the USA and Canada. Figure 2.4 identifies Region III and the other IIASA world regions. Japan and most of the countries of northern and southern Europe are in a position similar to that of the EC countries with regard to their medium- and long-term energy problems, and consequently have been treated in parallel by IIASA. The economic growth rates of all regions are given in Table 2.1 for the IIASA High and Low Scenarios. The MEDEE model (Khan and Hölzl 1980; Lapillonne 1978) calculations for Region III result in the demand spectra for secondary energy shown in Figures 2.5 and 2.6. On the basis of the estimated global availability of energy resources, the MESSAGE model (see Appendix)

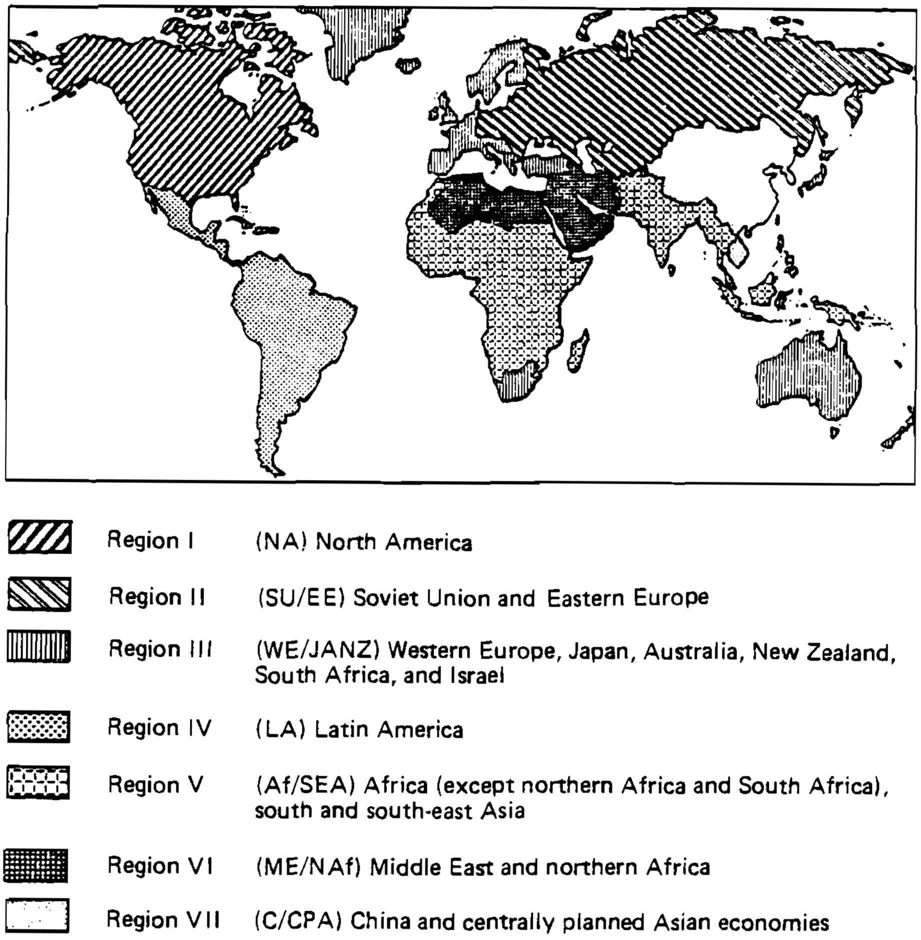

FIGURE 2.4 The seven world regions analyzed in the IIASA global energy study.

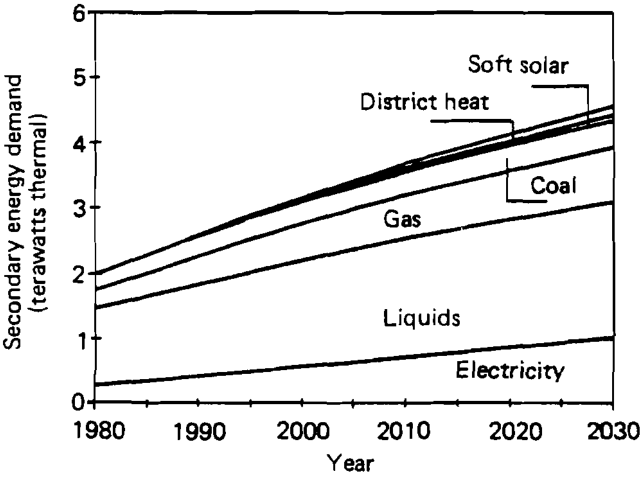

FIGURE 2.5 Secondary energy demand, IIASA Region III, High Scenario.

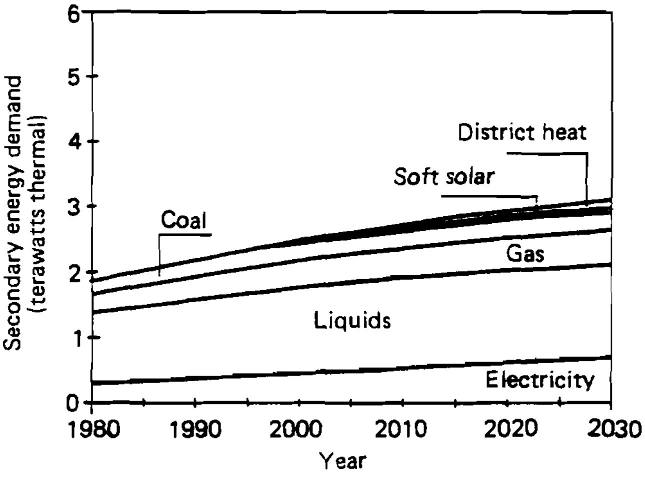

FIGURE 2.6 Secondary energy demand, IIASA Region III, Low Scenario.

allocates a cost-optimal primary energy supply to Region III, which draws heavily on energy imports. Figures 2.7 and 2.8 show the contributions of coal, oil, gas, nuclear power, and renewable energy resources to meeting the needs of Region III.

Figure 2.9 specifies the energy imports and exports of Region III in relation to the other oil-trading world regions. An abrupt transition in the allocation of energy exports from the resource-rich developing countries of Region IV (Latin America) and Region V (the Middle East and northern Africa) at about the turn of the century is forecast in both the IIASA scenarios. At this time Region V (central Africa, southern Asia, and parts of south-east Asia) switches from being a net exporter of energy to being a net energy importer. The present oil buying competition between Region I (North America) and

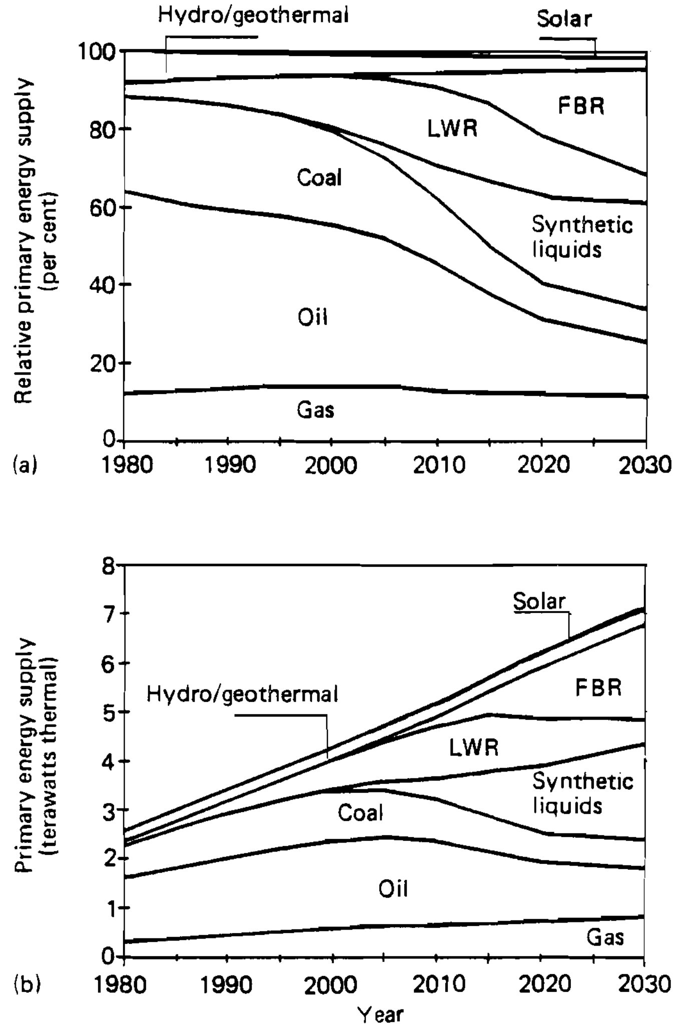

FIGURE 2.7 Primary energy supply, IIASA Region III, High Scenario. (a) Relative; (b) absolute. LWR, light water reactor; FBR, fast breeder reactor.

Region III (Western Europe, Japan, Australia, New Zealand, South Africa, and Israel) would presumably then be succeeded by competition between Region III and Region V. If Region I does not succeed in reducing its oil imports essentially to zero by this time, the competition between developed and developing countries for imported oil could become even sharper. The timing of the expected transition differs by only a few years in the High Scenario and in the Low Scenario.

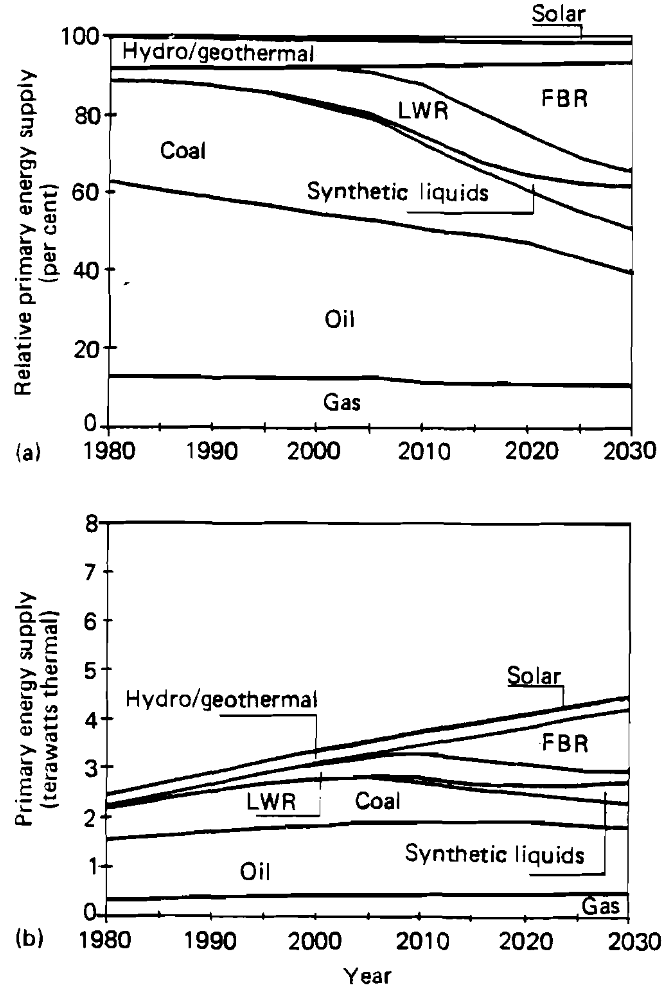

FIGURE 2.8 Primary energy supply, IIASA Region III, Low Scenario. (a) Relative; (b) absolute. LWR, light water reactor; FBR, fast breeder reactor.

The total import dependence of Region III, including coal and gas imports, is shown in Figure 2.10. The main features of the evolving supply system of Region III are clearly a shift from the strong dependence on oil imported from the OPEC countries to an equally strong dependence on coal and gas originating from North America, Eastern Europe, and the Soviet Union. Neither EC imports, nor imports into Japan, from Australia and South Africa show up in the import volumes of Region III; Australia, South Africa, and Norway are included in Region III, and consequently their resources contribute to the indigenous production of this region, even when these are traded between countries within the region.

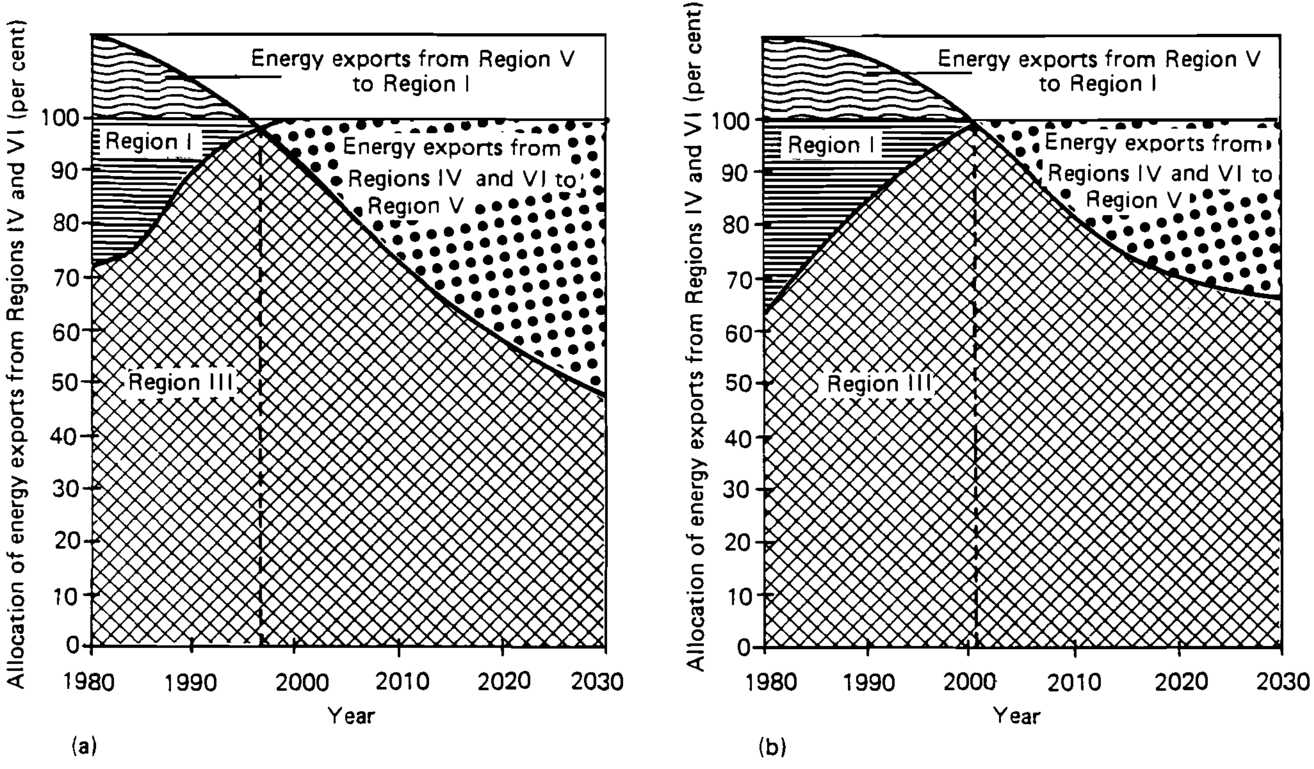

FIGURE 2.9 Exports of energy to IIASA Region III from the Middle East, northern Africa, and Latin America: (a) High Scenario; (b) Low Scenario.

TABLE 2.1 Projections of gross domestic product growth influenced by the energy problem: the IIASA High and Low Scenarios. Note: all growth rates are average annual growth rates (rounded) over the time period shown; actual projections show declining growth rates.

Region	Historical growth rate of per capita GDP, 1950–1975 (per cent per year)	GDP per capita, 1975 (US dollars)	Projected growth rate of per capita GDP (per cent per year)			
			High Scenario		Low Scenario	
			1975–2000	2000–2030	1975–2000	2000–2030
I (NA)	1.9	7,046	2.9	1.8	1.7	0.7
II (SU/EE)	6.7	2,562	3.6	3.2	3.1	1.9
III (WE/JANZ)	4.0	4,259	3.0	1.8	1.7	0.9
IV (LA)	2.9	1,066	3.0	2.4	1.6	1.9
V (Af/SEA)	2.5	239	2.8	2.4	1.7	1.4
VI (ME/NAf)	5.7	1,429	3.8	2.8	2.4	1.2
VII (C/CPA)	5.1	352	2.8	2.4	1.6	1.4

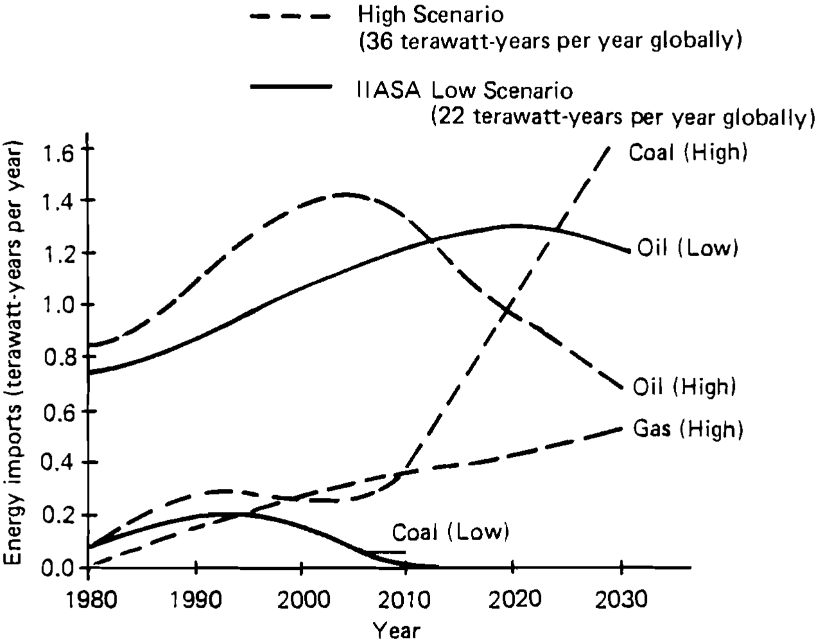

FIGURE 2.10 Energy imports of Region III in the IIASA High and Low Scenarios.

Table 2.1 and Figures 2.5–2.10 quantify possible evolutions of the energy systems of a larger group of countries than just those members of the EC. It is repeated here that any assessment or any comparison with projections by or for the EC has to take note of the objectives that guided the development of these scenarios; these objectives have been outlined earlier in the comparative description of the methodological approach. Readers desiring more information are referred to the specific details reported in the 850-page reference volume of the IIASA study, *Energy in a Finite World* (Energy Systems Program Group of IIASA 1981).

2.3 The Long-Term EC Energy Scenarios

Starting from demographic projections together with projections concerning labor markets, a high and a low economic growth path were identified for the EC. These projections include extrapolations of labor productivity and trends observed before 1975, as well as judgments on long-term economic saturation effects. In Figure 2.11 a high and a low growth path of gross domestic product (GDP) are given. They embrace a range of possible developments that were considered feasible in the light of the interdependence of labor markets and macroeconomic outputs observed in the past behavior of the EC economies. Together with projections of technological changes in the various consuming sectors of the EC economies, the high and the low economic growth paths translate into alternative evolutions of final energy demand (Figure 2.12). Initially moderate and later high energy conservation rates were combined with the high economic growth path, whereas the low economic growth path assumed a high degree of conservation from the

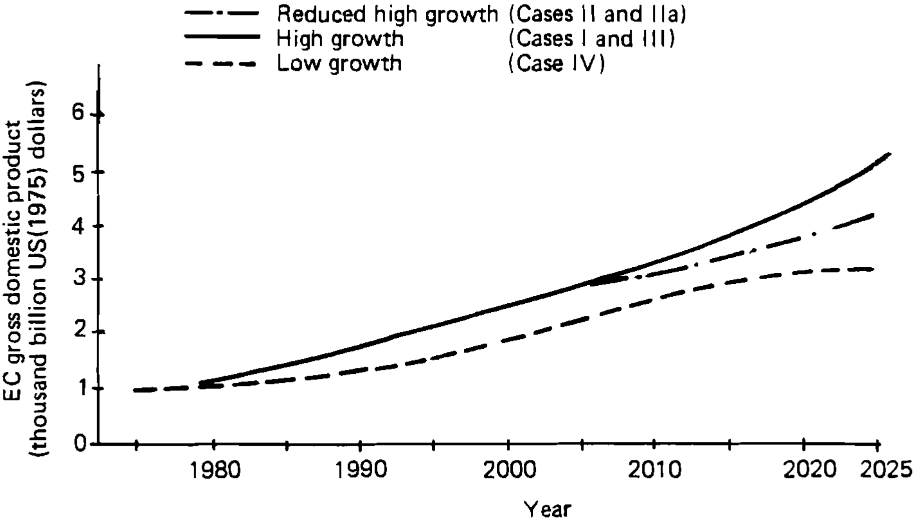

FIGURE 2.11 Growth of the gross domestic product of the EC, alternative cases. Source: Commission of the European Communities (1980).

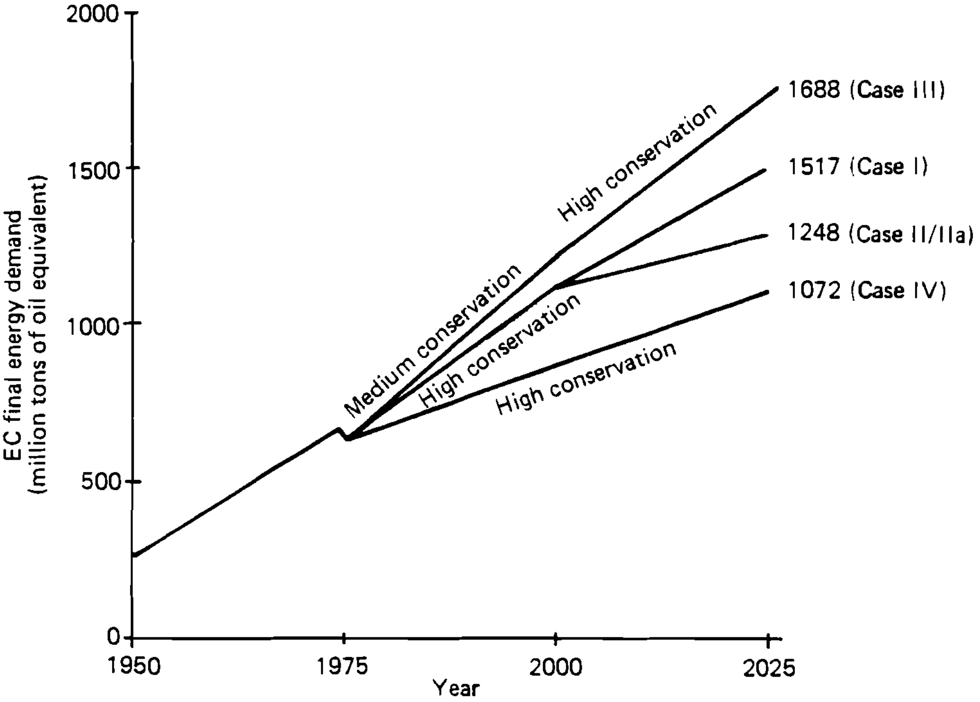

FIGURE 2.12 Evolutions of EC final energy demand. Source: Commission of the European Communities (1980).

base year 1975 onward. As a result of the difficulties encountered during the analytical efforts to meet these demands within technical and policy constraints on the energy supply system of the EC, two further demand cases were subsequently added. These are also shown in Figure 2.12. Here the energy savings through conservation efforts in the high growth case are augmented by a slower growth in energy demand due to a reduction in the economic growth potential beyond the year 2000. The various cases combine alternative technological strategies, i.e. projections of more or less successful deployment of the various energy supply chains, together with invariably optimistic estimates of indigenous resources and import quantities of oil, gas, coal, and uranium. However, normative assumptions about the maximum tolerable overall dependence on energy imports, as well as about a balanced relationship between the contributions of individual primary energy forms, appeared necessary in order to limit the strain on the supply technologies. Of the five cases that were ultimately quantified, Case IIa is of particular importance. It is termed the Acceptable Dependence Case to underline the fact that it provides for a balanced energy supply system, complying with the two assumed policy goals of the EC of a maximum dependence on energy imports of less than 50% and a limit to the contribution of any one primary energy carrier of 30% of the total supply. The price of this balanced supply is a reduced economic growth potential and a high energy conservation requirement. The supply structure of this case is given in Figure 2.13. A careful analysis of the different scenarios reveals the lack of flexibility in a policy of compensating for delays in the deployment of any one energy source by drawing more heavily on an alternative source. In fact, the allocation of energy sources in the EC scenarios is determined only to a very small degree by energy price or cost relationships. Instead, the system is determined by the fixed economic goals and the total set of constraints that characterize the EC resource situation, by import expectations, and also by the economic structure and its maximum adjustment rate. Most crucially, these severe constraints arise despite comparatively high technical conservation projections and a rather optimistic assessment of energy imports with regard to both quantities and prices.

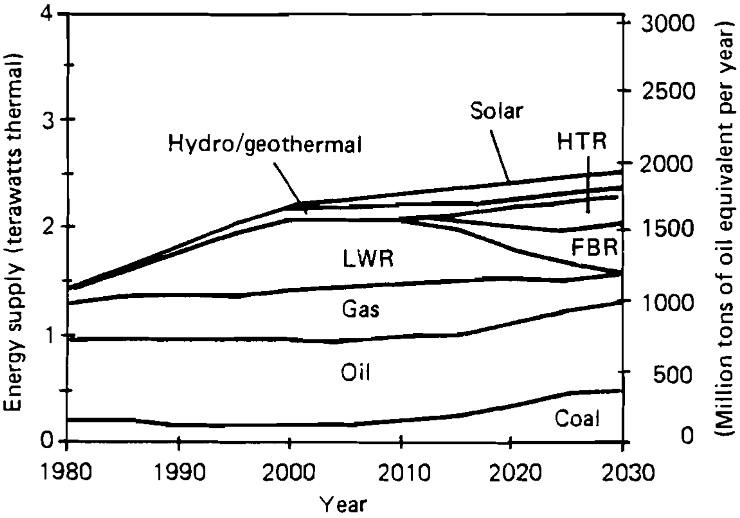

FIGURE 2.13 EC Acceptable Dependence energy supply case. Source: Commission of the European Communities (1980).

3 A COMPARISON OF THE GLOBAL AND THE EC SCENARIOS

To repeat here what was said in section 2.1, the IIASA scenarios and the EC scenarios must be seen as answers to different questions. Nevertheless, these answers do have a common basis. They derive from identical models and from data sets that are used in both analyses. Moreover, as the EC energy system constitutes a substantial part of the global energy system, it directly influences the "exogenous" conditions of the global energy markets subject to which EC energy strategies are formulated. The quantities of energy imported under such strategies must always fit into the global balance, taking account of the preparedness of all producers to export and the abilities of all consumers to import. The position of a group of countries such as the EC within the global energy trade pattern is not determined solely by energy price levels, either in reality or in the formalized scenario writing procedures. An economy, depending on the efficiency with which it can convert energy into marketable commodities, will be able to command a larger or smaller share of the limited global energy supply over a period of time. This would cause a correspondingly more or less severe energy problem elsewhere in the world, however.

A careful comparison of the global scenarios of the IIASA and the EC scenarios provides a first-order evaluation of the extent to which the estimates of realizable import volumes and conservation potentials in the EC scenarios described in section 2.3 indirectly rely on "exporting" the energy problem.

In order to draw such a comparison, it was necessary to disaggregate the IIASA Region III, i.e. the OECD countries excluding the USA and Canada, into the EC countries and a group comprising the remaining countries of Region III. For many reasons, the demand and supply pattern of the respective IIASA scenarios for Region III cannot just be disaggregated according to any fixed parameter ratios. Instead, two subscenarios had to be developed, specifying the possible evolution of the EC, in the first instance within the set of asssumptions determining the IIASA High Scenario, and in the second within those of the IIASA Low Scenario. For this process of scenario writing, the basic methodology of Figure 2.1 was implemented in a specialized form. It deviates distinctly from the iterative procedure outlined in Figure 2.2. Figure 3.1 indicates the main steps of disaggregation that led to the two scenarios, labeled IIASA/EC High and Low. The hypothesis needed to "allocate the global energy problem" between the EC countries and the other countries of Region III relates to the relative economic growth potentials of these two competing groups of industrialized countries. In line with the energy conservation assumptions in the IIASA scenarios for Region III, structural evolutions for the different economic sectors were fixed in order to ensure comparable overall economic energy elasticities for both subregions as well as to conform to the fixed aggregate gross domestic product (GDP) evolution and final energy demand figures for Region III. The details of this step are explained in section 3.1.1.

The determination of the supply parts of the IIASA/EC High and Low Scenarios involved less additional normative information. Here the ambiguities reside more or less in the allocation of the oil import volumes for Region III and in the availability of uranium. The allocation can mainly be assessed through the resulting total supply pattern for the two subregions. The tendency was to select a more favorable allocation for the EC, driving the other Region III countries into a faster nuclear build-up and higher coal utilization shares than the EC. The resulting supply scenarios are specified in section 3.1.2.

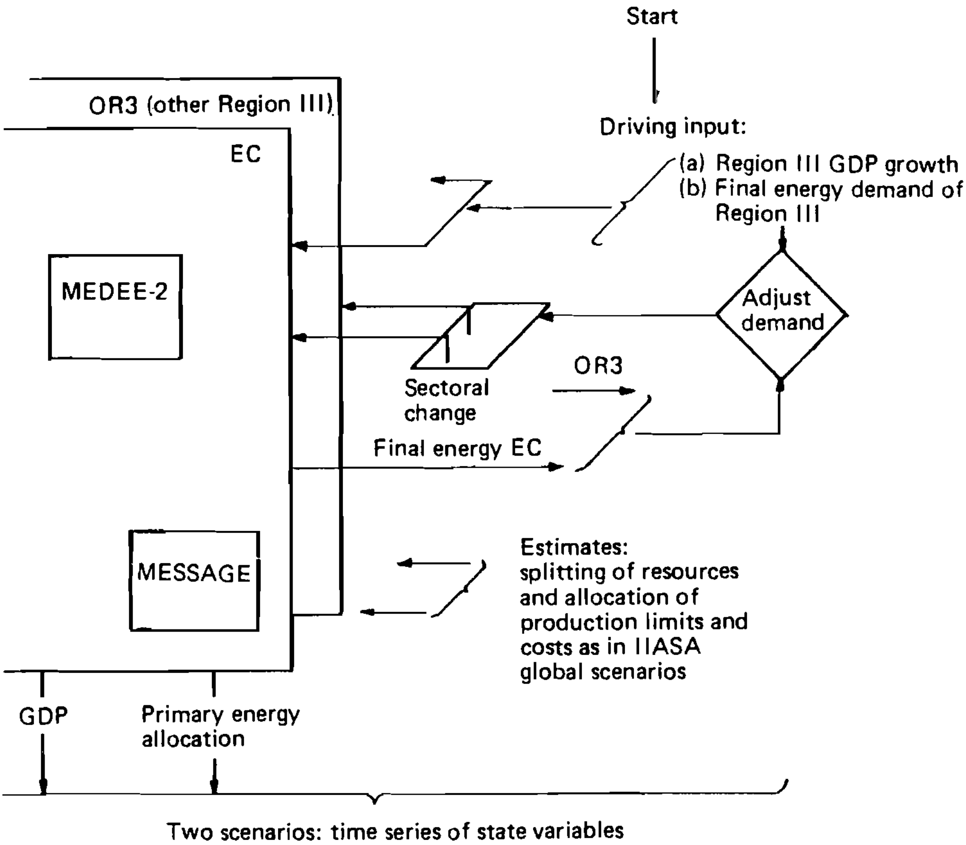

FIGURE 3.1 The process of scenario writing: IIASA/EC High and Low Scenarios.

The availability of top-down scenarios, here the IIASA/EC scenarios, and the bottom-up scenarios of *Crucial Choices for the Energy Transition* (Commission of the European Communities 1980) allowed a direct comparison of the projections of different state variables. The substantial discrepancies are explained in section 3.2.

3.1 The EC as a Subregion of the Global Energy System

3.1.1 The Evolution of Final Energy Demand

The main features of the IIASA scenarios are summarized in section 2.1. The scenarios are described in more detail in Part IV of *Energy in a Finite World*. Regional disaggregation had to be limited in that study: the presently developed market economies (mostly OECD countries) were divided into just two sets, namely Region I (North America) and Region III (OECD countries excluding North America, together with a few non-OECD

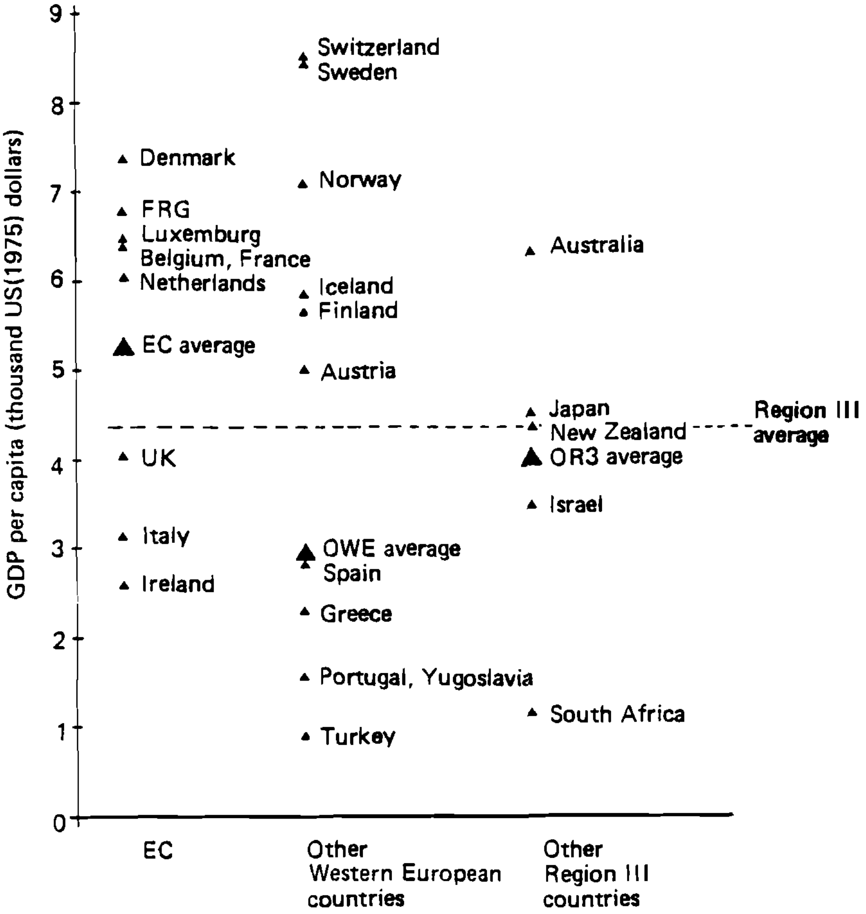

FIGURE 3.2 The distribution of GDP per capita in 1975 for Region III and subregions. Source: OECD (1979a).

countries such as Yugoslavia, South Africa, and Israel). Naturally, Region III is a very inhomogeneous set of countries, geographically, politically, and economically. A further subdivision singling out EC countries distinguishes three groups for the final demand assessment: EC, the member countries of the European Communities in 1975; OWE (other Western European countries); and OR3 (other Region III countries). Figure 3.2 shows the distribution of GDP per capita in 1975 for these groups. The ranges are US$2600–7400* for the EC, US$900–8500 for OWE, and US$1200–6300 for OR3. Although this subdivision reduces the geographical and political inhomogeneity, the disparity in terms of economic development remains in all three subregions, but especially in OWE.

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*All monetary units in this report are given in US dollars at 1975 prices and calculated using 1975 exchange rates.

The population projections for the three subregions are shown in Figure 3.3. They were supplied by Keyfitz (1977) on a country-by-country basis. The aggregate corresponds to the population evolution used in the scenarios for Region III. Although the population of Region III is expected to increase from 560 million in 1975 to 767 million by 2030, this Region's proportion of world population decreases from 19% to 10%. Within Region III, the EC shows the lowest rate of population growth, with an expected increase in population from 258 million in 1975 (46% of Region III) to 304 million by 2030 (40% of Region III). The potential labor force – i.e. the percentage of the population between fifteen and sixty-four years old – remains fairly constant in the EC (64%) and OR3 (65%), but increases in OWE from 61% in 1975 to 66% by 2030.

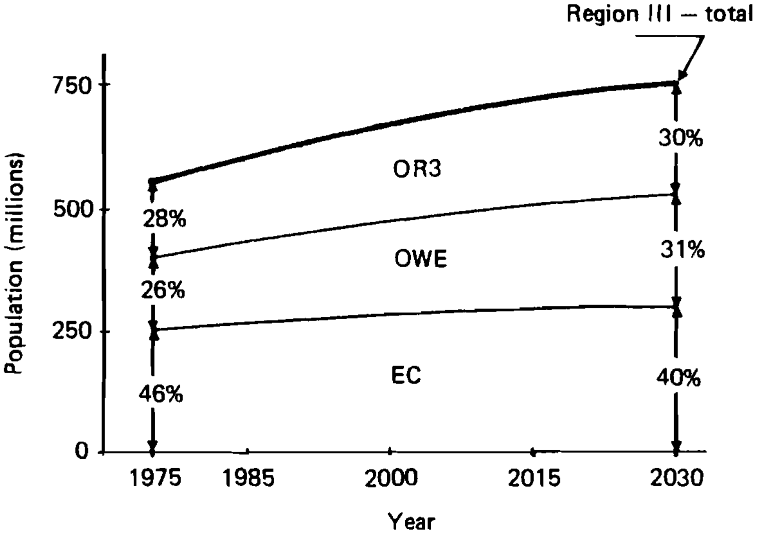

FIGURE 3.3 Population projections for Region III and subregions. Source: Keyfitz (1979).

The gross domestic product (GDP) growth projections were originally estimated not for each country individually but for the OECD countries (excluding North America) in aggregate. Figure 3.4 shows the evolution of the GDP shares of the three subregions in the total GDP of Region III between 1963 and 1977. The share of the EC declined steadily from 65% to 57%, and that of OWE remained almost constant (16–17%), while OR3 – which is dominated by Japan – increased its share from 18% to 26%. The different economic growth potentials of the past are likely to persist into the future; at least, there are no straightforward arguments suggesting a reversal of such trends. The contributions of the subregions to the total economic output of Region III were therefore assumed to change in accordance with the overall growth potential of each region. Transition matrices were estimated both from observations for the whole period 1963–1977 and from observations for 1968–1977.

The projected increase in the total GDP of IIASA's Region III, from US(1975)$2400 billion in 1975 to US(1975)$11,700 billion in 2030 (High Scenario), translates into a decline in the GDP share of the EC from 57% to 46% (using a transition matrix based on the period 1963–1977) or from 57% to 51% (using a transition matrix based on the period 1968–1977). Because of Japan's heavy reliance on raw material imports and exports of

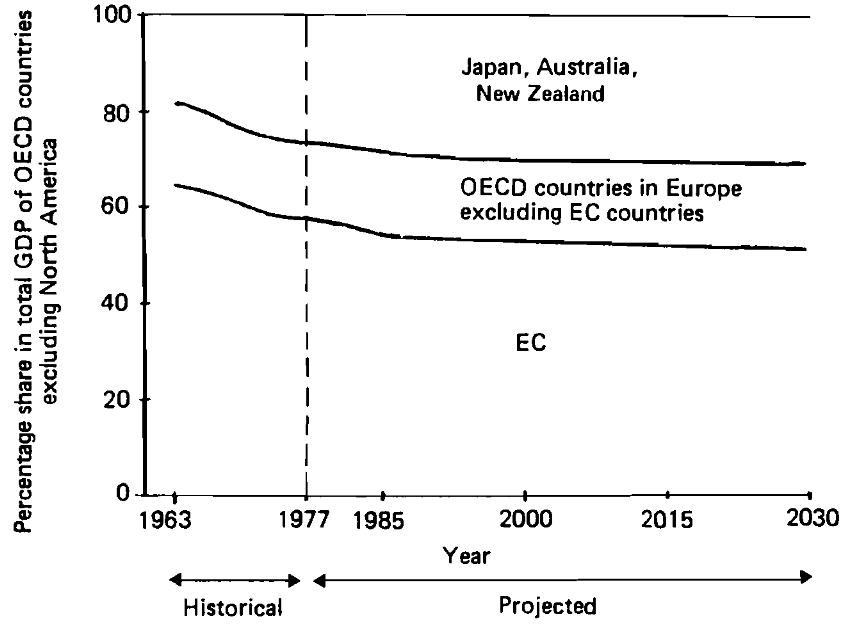

FIGURE 3.4 Projection of GDP shares for the EC within Region III (IIASA/EC High Scenario). Source: based on OECD (1979b).

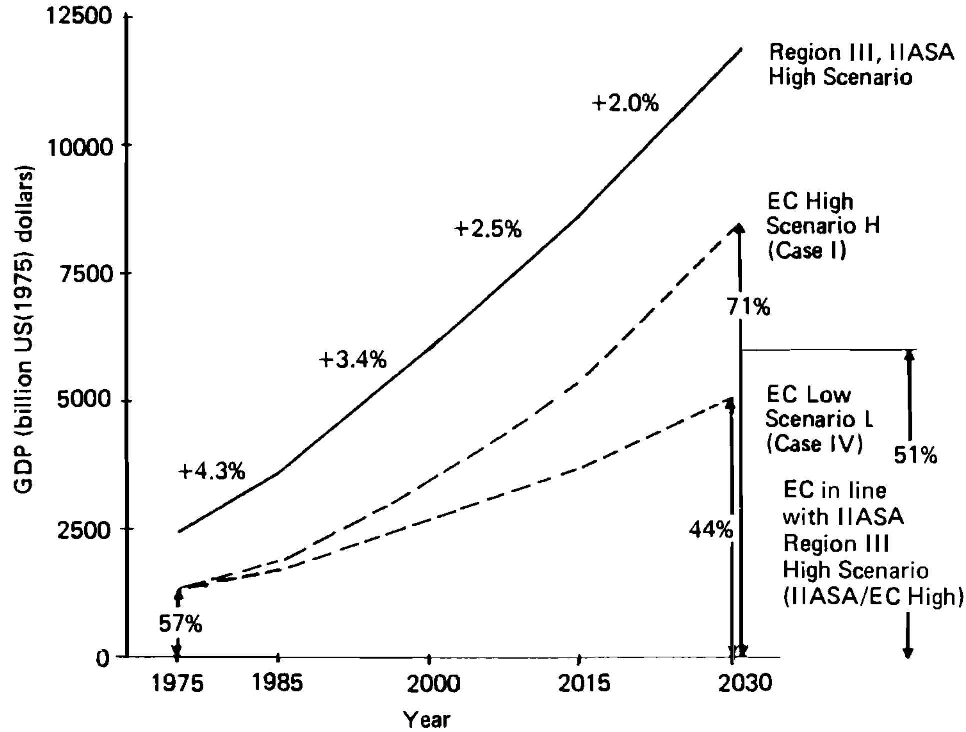

FIGURE 3.5 GDP projection for Region III, IIASA High Scenario, compared with EC Cases I (H) and IV (L).

manufactured goods, and the difficulties expected in the future in these areas, it was considered reasonable to choose the latter matrix for the projections. This implies a continuation of higher growth in Japan than in other Region III countries, but a considerably less favorable development than that suggested by the evolution in the early 1960s.

On comparing the GDP growth assumptions of the EC High (H) and Low (L) Scenarios in *Crucial Choices for the Energy Transition* (Commission of the European Communities, 1980) with the IIASA High Scenario projections for Region III (see Figure 3.5), it turns out that the IIASA High Scenario for Region III is close to the EC low growth scenario (Case IV). This discrepancy points either to pessimism in the IIASA scenarios or to substantial optimism in the EC scenarios.

Figure 3.6 shows the GDP growth rates for the IIASA/EC cases derived from the IIASA Region III projections. These are reasonably consistent with the growth rates projected for the other IIASA regions, but they seem hardly acceptable on a national level. Nevertheless, these low economic growth rates were considered necessary in order to match energy demand and supply on a global level.

Tables 3.1–3.3 summarize the GDP growth projections for Region III and those derived for the EC. Between 1975 and 2030 the GDP of Region III increases by a factor of 2.8–4.9, and that of the EC by a factor of 2.5–4.2. On a per capita basis, however, the EC would still have a slightly higher GDP growth rate than other Region III countries.

For an assessment of energy demand, in addition to the evolution of total GDP, the growth rates of various sectors have to be projected. Within the framework of MEDEE-2, the sectoral breakdown of energy demand is as follows (for a summary description of MEDEE-2 see Chateau and Lapillonne 1977; Lapillonne 1978; and Khan and Hölzl 1980):

- production of goods
- freight transportation
- passenger transportation
- households
- service sector.

The goods-producing sector is further divided into

- agriculture
- construction
- industry (excluding energy producers)
- energy producers (for accounting purposes only; their energy demand is not treated in MEDEE-2).

Within agriculture and construction, the essential energy demand is for motor fuel; electricity and thermal energy use are not generally very significant in these sectors.

Industries (excluding energy producers) are classified into three categories, namely industries producing predominantly

- basic materials
- machinery and equipment
- nondurable goods.

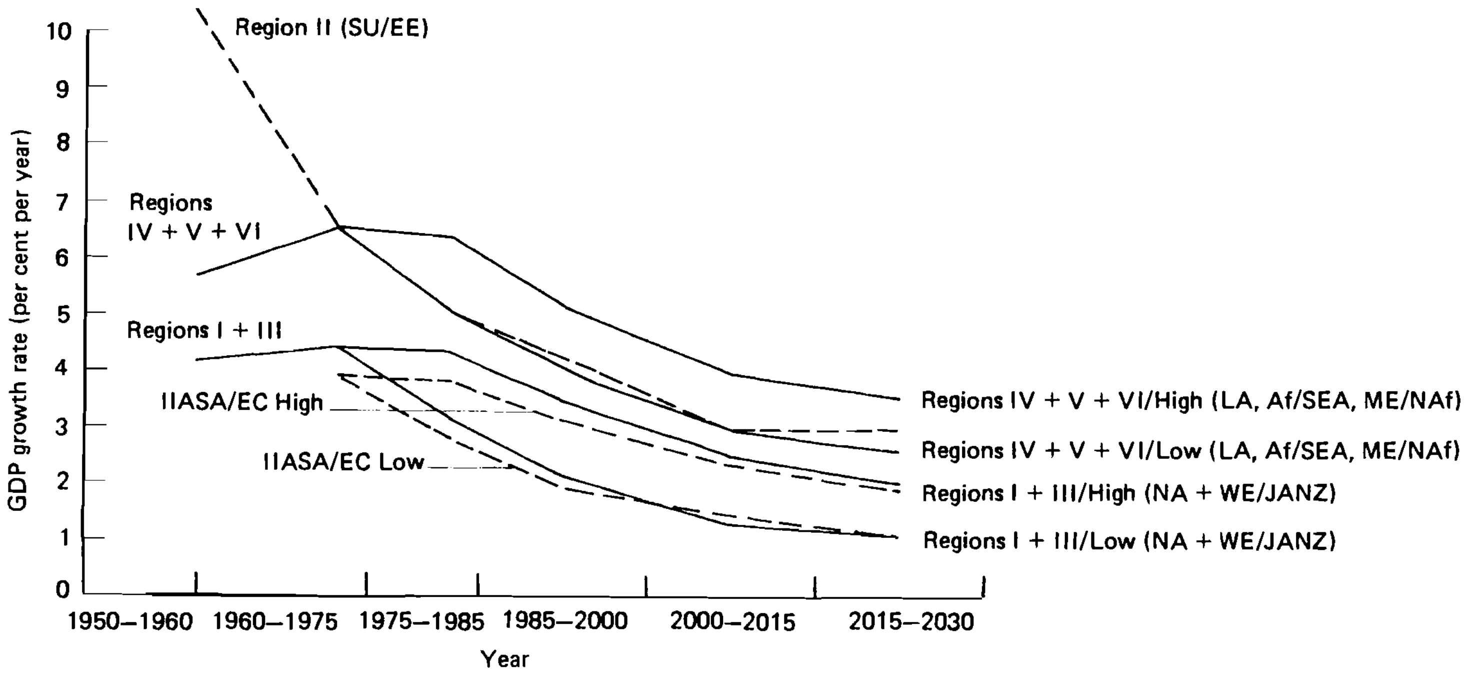

FIGURE 3.6 Historical and projected GDP growth rates.

TABLE 3.1 Annual GDP of IIASA/EC and IIASA Region III, 1975–2030.

	GDP (thousand billion US(1975) dollars)				
	1975	1985	2000	2015	2030
High Scenario					
Region III	2.4	3.6	6.0	8.7	11.7
IIASA/EC	1.4	2.0	3.2	4.5	6.0
percentage of Region III	57	54	53	52	51
Low Scenario					
Region III	2.4	3.3	4.5	5.6	6.7
IIASA/EC	1.4	1.8	2.4	2.9	3.5
percentage of Region III	57	55	53	53	52

TABLE 3.2 GDP per capita for IIASA/EC and IIASA Region III, 1975–2030.

	GDP per capita (thousand US(1975) dollars)				
	1975	1985	2000	2015	2030
High Scenario					
Region III	4.3	5.9	8.8	12.0	15.2
IIASA/EC	5.3	7.3	11.1	15.3	19.8
Low Scenario					
Region III	4.3	5.3	6.5	7.7	8.7
IIASA/EC	5.3	6.7	8.3	9.9	11.5

TABLE 3.3 Average annual GDP growth rates for IIASA/EC and Region III.

	Annual GDP growth rate (per cent per year)			
	1975–1985	1985–2000	2000–2015	2015–2030
High Scenario				
Region III	4.30	3.40	2.50	2.00
IIASA/EC	3.84	3.16	2.40	1.95
Low Scenario				
Region III	3.17	2.10	1.50	1.20
IIASA/EC	2.82	1.91	1.41	1.16

The first category includes mining (excluding coal, oil, and gas), basic metal industries, nonmetallic mineral products, chemicals (excluding petroleum and coal products), and the paper and pulp industry. It is characterized by a high energy demand per unit output, for both electricity and thermal uses. The thermal energy demand of the basic metal and building material industries is mostly in the high temperature range (furnace), while the chemical and paper industries have a high demand for steam. The other two industry categories have relatively modest energy intensities: the machinery and equipment sector's thermal energy demand is in the medium-to-high temperature range (metal treatment), while the nondurable goods industries have a high demand for steam and hot water. In the latter two categories, space heating is also important.

Table 3.4 shows the growth rates of the various sectors assumed for Region III and for the EC in the High and Low Scenarios. A common feature is a significantly below average growth rate for agriculture, an above average growth rate in the service sector, and a slightly below average growth rate for industry. Within industry, basic materials and nondurables are expected to have below average growth rates, and the machinery and equipment sector to grow at the same rate as the GDP.

TABLE 3.4 Growth rates in value-added assumed for the EC and for Region III (per cent per year, 1975–2030).

	EC		Region III	
Sector	IIASA/EC High	IIASA/EC Low	High	Low
Agriculture	1.7	1.2	1.4	0.7
Construction	2.7	1.7	2.7	1.8
Industry (excluding energy)				
Basic materials	2.5	1.5	2.3	1.4
Machinery and equipment	2.7	1.7	3.0	1.9
Nondurables	2.6	1.6	2.2	1.5
Energy	3.0	1.9	3.1	2.1
Services	2.9	1.8	3.3	2.1
Total GDP	2.7	1.7	2.9	1.9

The structural changes implied by these growth rates, in addition to efficiency improvements and fuel mix changes, contribute to the fall in the average energy intensity of manufacturing industries, as detailed in Tables 3.5 and 3.6. The annual rate of reduction of energy intensity (i.e. kilowatt-hours per US (1975) dollar GDP) is 0.9% for Region III and 1.5% for the EC in the period 1975–1985, but is expected to decrease to values of 0.4% (Low Scenario) or 0.6–0.7% (High Scenario). We adopted a higher value in the High Scenario, assuming a quicker renewal of capital stock under these conditions than in a low growth environment. The higher rate for the EC reflects the fact that there should be more scope – or rather a greater necessity – for reducing energy consumption in these countries than in Japan with its modern industry.

The reduction of industrial energy intensity is shown in Table 3.6. This technological assumption might appear modest when compared with the 2.2% annual reduction achieved by the EC during the period 1960–1976, even more so the 2.7% per year in the USA and

TABLE 3.5 Average energy intensity of manufacturing industries in the EC and in IIASA Region III, 1975–2030.

	Average energy intensity of manufacturing industry (watt-years per US(1975) dollar GDP)				
	1975	1985	2000	2015	2030
Region III	0.91	0.83	(0.75–0.74)	(0.70–067)	(0.66–0.61)
IIASA/EC	1.00	(0.87–0.86)	(0.77–0.75)	(0.70–0.67)	(0.66–0.60)

TABLE 3.6 Average annual rate of reduction in energy intensity of manufacturing industries in the EC and in IIASA Region III, 1975–2030.

	Average annual rate of reduction in energy intensity (per cent per year)			
	1975–1985	1985–2000	2000–2015	2015–2030
Region III	0.92	(0.67–0.76)	(0.46–0.66)	(0.39–0.62)
IIASA/EC	(1.47–1.50)	(0.81–0.91)	(0.63–0.75)	(0.39–0.73)

Japan. On the other hand, high growth rates, together with the shift from a coal-based energy system to one relying mostly on oil and gas, certainly played a major part in the rapid reduction, and similar opportunities are not to be expected in the future.

Table 3.7 summarizes the assumptions in the scenarios concerning freight transportation. Total activity is linked to GDP excluding services, i.e. the GDP contributions of the goods-producing sectors. Electricity consumption is converted to its primary energy equivalent for purposes of comparison. In the Region III scenarios, both the fuel mix and the energy intensities were kept constant because of the uncertainties in the base year values. In the IIASA/EC scenarios a significant shift to rail is introduced, leading to a decline in the average energy intensity, as shown in Table 3.7. Motor fuel consumption for international transportation and for military use is assumed to grow in proportion to GDP. Freight transportation accounts at present for about 24% of the total energy demand for transportation in the EC; this share increases to 31–34% in the scenarios. The share of

TABLE 3.7 Freight transportation: summary characteristics.

	IIASA/EC			Region III		
		2030			2030	
	1975	High	Low	1975	High	Low
Activity (10^9 ton-kilometers)	0.63	2.51	1.51	1.52	6.02	3.67
GDP excluding services (thousand billion dollars)	0.62	2.49	1.50	1.23	4.91	3.00
Unit cost (ton-kilometers per US(1975) dollar)	1.00	1.00	1 00	1.20	1.20	1.20
Energy intensity (kilowatt-hours per ton-kilometer)[a]	0.59	0.52	0.52	0.61	0.60	0.60
Energy consumption (gigawatt-years[b] per year)[a]	42.6	148.6	88.8	105.0	415.2	253.0
Share of total transportation energy (per cent)	24	34	31	32	35	34
Energy consumption including international transportation and military use (gigawatt-years[b] per year)[a]	51.6	188.5	111.9	127.2	523.8	314.8
Share of total transportation energy (per cent)	30	44	39	39	44	42

[a] Electricity consumption converted to primary energy equivalent.
[b] 1 gigawatt = 10^9 watts.

energy required for international transportation and military use increases from 6% in 1975 to 8–10% by 2030. In Region III the initial share is higher than 6% because of the lower level of car ownership outside the EC, but it increases more slowly to a figure similar to that for the EC in 2030.

Passenger transportation is not formally linked to an economic indicator in MEDEE-2, although a correlation between travel intensity and GDP per capita certainly exists. For IIASA/EC, it is assumed that the travel intensity will increase from 9600 kilometers per person per year to 17,000–20,000 km per person per year by 2030; the corresponding assumption for Region III was an increase from 9200 to 14,000–18,000 km per person per year. In the EC, car ownership increases from 270 to 400–500 per thousand persons by 2030, and in Region III from 190 to 310–450 by 2030. Whereas for cars a saturation of ownership and accordingly of total distance traveled can already be foreseen, air travel is only now becoming more widespread. Its share of total passenger-kilometers is assumed to increase to 6–12%.

A major increase (30–40%) in the fuel efficiency of cars is assumed for both IIASA/EC and Region III; in Region III, the shift to more energy-intensive modes (car and plane) offsets these improvements, while in the EC, with its present high share of car transportation, mass transit modes (train and bus) are assumed to increase their shares, contributing to a further reduction in the average energy intensity of passenger travel. The characteristics are summarized in Table 3.8.

The household/service sector energy demand in industrialized countries is dominated by space heating. The large increase in space heating in the past was mainly due to the trend to central heating of the total residential floor area rather than just the living room. At present about 50% of dwellings in the EC and about 30% of dwellings in Region III as a whole are centrally heated. By 2030, the figure for the EC is assumed to be 100% in the High Scenario. The continued trend to central heating partly offsets the reductions in space heating demand that can be expected as a result of better insulation. Air conditioning is disregarded as a major consumer of energy in all EC scenarios. Electricity demand for household appliances is expected to increase, however, from 1500 kilowatt-hours per

TABLE 3.8 Passenger transportation: summary characteristics.

	IIASA/EC			Region III		
		2030			2030	
	1975	High	Low	1975	High	Low
Activity (10^9 passenger-kilometers)	2.98	5.97	5.06	5.17	13.8	10.7
Travel intensity (thousand kilometers per year)	9.6	19.7	16.6	9.2	18.0	14.0
Proportion by car (per cent)	82	65	64	37	50	43
Proportion by plane (per cent)	1	12	6	3	11	6
Energy intensity (kilowatt-hours per passenger-kilometer)[a]	0.43	0.36	0.31	0.34	0.42	0.35
Sectoral energy consumption (gigawatt-years[b] per year)[a]	122.6	242.4	177.7	198.0	657.4	427.5
Share of transportation energy (per cent)	70	56	61	61	56	58

[a] Electricity consumption converted to primary energy equivalent.

[b] 1 gigawatt = 10^9 watts.

dwelling per year to 4500–6000 per dwelling per year in the EC. The present figure given for Region III for this demand appears overestimated; on the other hand, the electricity consumption of the service sector was underestimated (see Tables 3.9 and 3.10).

The results of the MEDEE calculations with the sectoral and technological changes described are given in Figures 3.7 and 3.8. Figure 3.7 shows the sectoral shares in consumption and the shares in supply of various energy forms in the High Scenario for the EC and for Region III. In both cases the share of the household/service sector decreases as a result of relatively low population growth, saturation tendencies in some demand categories, and better system performance. Whereas for Region III this reduced share is offset by the increasing share of the transportation sector, this sector's share remains constant for the EC, and the industry share increases instead. Although electricity is assumed to penetrate only moderately into thermal uses in these scenarios, the electricity share increases by about 60% in Region III and by about 80% in the EC. Demand for motor fuel

TABLE 3.9 Households: summary characteristics.

	IIASA/EC			Region III		
		2030			2030	
	1975	High	Low	1975	High	Low
Persons per dwelling	2.98	2.30		3.00	2.56	
Number of dwellings (millions)	86	132		187	300	
Useful energy per dwelling (thousand kilowatt-hours per year)	18.3	24.5	21.6	12.7	20.6	17.5
Space and water heating (per cent)	88	72	75	75	62	65
Cooking (per cent)	4	3	4	10	6	7
Air conditioning (per cent)	–	0	0	–	3	2
Electrical appliances (per cent)	8	25	21	15[a]	29	26
Total sectoral useful energy (gigawatt-years per year)	180	369	325	272[a]	705	600

[a] Electricity use for electrical appliances was considerably overestimated in the base year (1975) for Region III; electricity use in the service sector was underestimated.

TABLE 3.10 Service sector: summary characteristics.

	IIASA/EC			Region III		
		2030			2030	
	1975	High	Low	1975	High	Low
Floor area per worker (square meters)	29	42	38	28	35	32
Total area (10^9 square meters)	1.75	3.41	3.00	3.00	7.26	6.00
Useful energy per square meter (thousand kilowatt-hours per square meter per year)	0.28	0.26	0.23	0.15	0.21	0.19
Specific electricity (per cent)	25	37	33	26[a]	50	47
Air conditioning (per cent)	1	9	7	2	4	3
Thermal uses (per cent)	74	54	60	72	46	50
Total sectoral useful energy (gigawatt-years per year)	57	101	81	52[a]	172	130

[a] Electricity use for electrical appliances was considerably overestimated in the base year (1975) for Region III; electricity use in the service sector was underestimated.

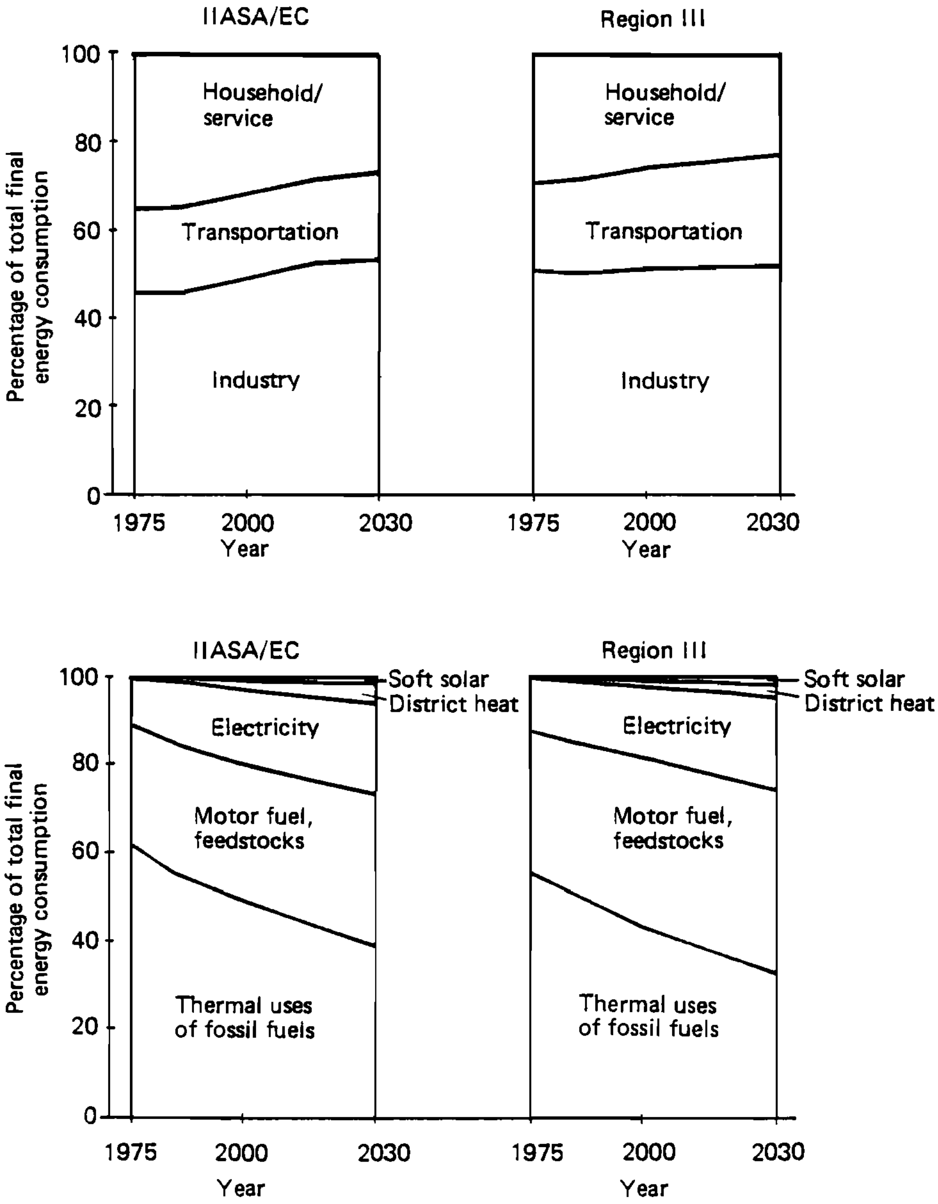

FIGURE 3.7 Consumption of final energy by sector and by use (High Scenario).

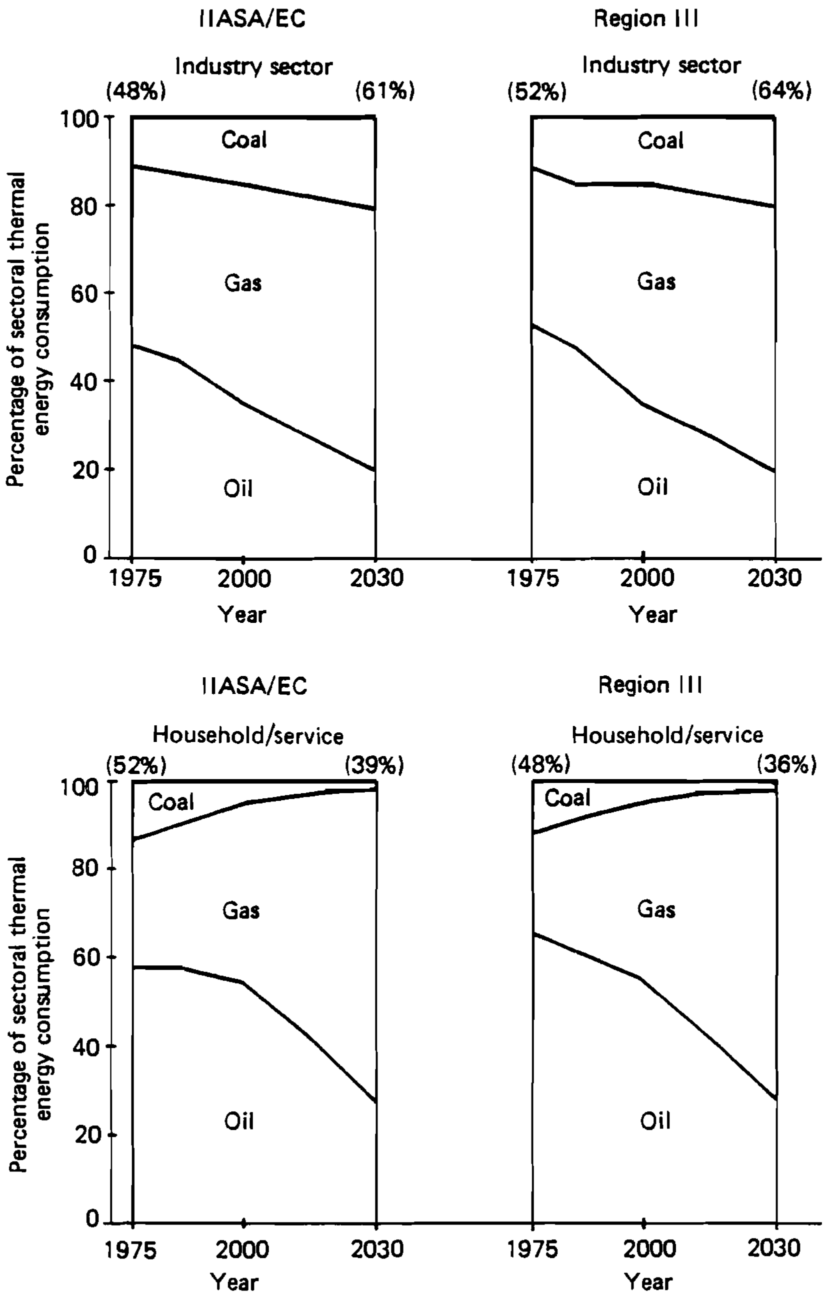

FIGURE 3.8 Assumed mix of fossil fuels for thermal uses (High Scenario). The percentages in parentheses are the sectoral shares in total energy consumption in 1975 and 2030.

and feedstocks also increases considerably, while the share of fossil fuels for thermal uses declines from 60% to 40% in the EC and from 55% to 35% in Region III. It was assumed that coal use would increase in industry, but that its inconvenience would further diminish its share in the household/service sector. The main substitute for oil for thermal uses is expected to be gas (see Figure 3.8).

Although the energy demand assessment was made on the basis of specific sectoral and technological assumptions, the uncertainty in many details necessitates a feasibility check on an aggregate level. Table 3.11 and Figure 3.9 present some aggregate indicators of the evolution outlined in these scenarios. In the High Scenario, final energy consumption per capita increases by 80% in the EC and doubles in Region III between 1975 and 2030; in the Low Scenario, only a moderate increase, by 29% or 37% respectively, occurs. On the other hand, the final-energy-to-GDP ratio in the Low Scenario is reduced by about 50%; notwithstanding the strong increase in the share of electricity, this evolution implies a significant reduction in relative energy demand in comparison with past trends, as shown in Figure 3.9.

TABLE 3.11 Summary of final energy demand projections for IIASA/EC and IIASA Region III, 1975–2030 (the first value is for the High Scenario, the second for the Low Scenario).

	1975	1985	2000	2015	2030
Final energy (terawatt-years per year)					
Region III	1.59	1.96–2.20	2.39–3.03	2.74–3.77	2.99–4.37
IIASA/EC	0.91	1.05–1.13	1.17–1.43	1.27–1.70	1.38–1.93
(Percentage of Region III)	57	53–52	49–47	46–45	46–44
Electricity share (percentage of final energy)					
Region III	13	14	17	19	21
IIASA/EC	11	14	17	19	20
Final energy per capita (kilowatts per capita)					
Region III	2.84	3.21–3.59	3.52–4.46	3.77–5.18	3.90–5.70
IIASA/EC	3.53	3.90–4.20	4.09–5.02	4.31–5.78	4.54–6.35
Final-energy-to-GDP ratio (watt-years per US (1975) dollar)					
Region III	0.67	0.60–0.60	0.54–0.51	0.49–0.43	0.45–0.37
IIASA/EC	0.67	0.59–0.57	0.49–0.45	0.43–0.38	0.40–0.32

	1975–1985	1985–2000	2000–2015	2015–2030
Final-energy-to-GDP elasticity				
Region III	0.68–0.77	0.64–0.65	0.60–0.59	0.49–0.50
IIASA/EC	0.50–0.57	0.38–0.51	0.41–0.49	0.47–0.43

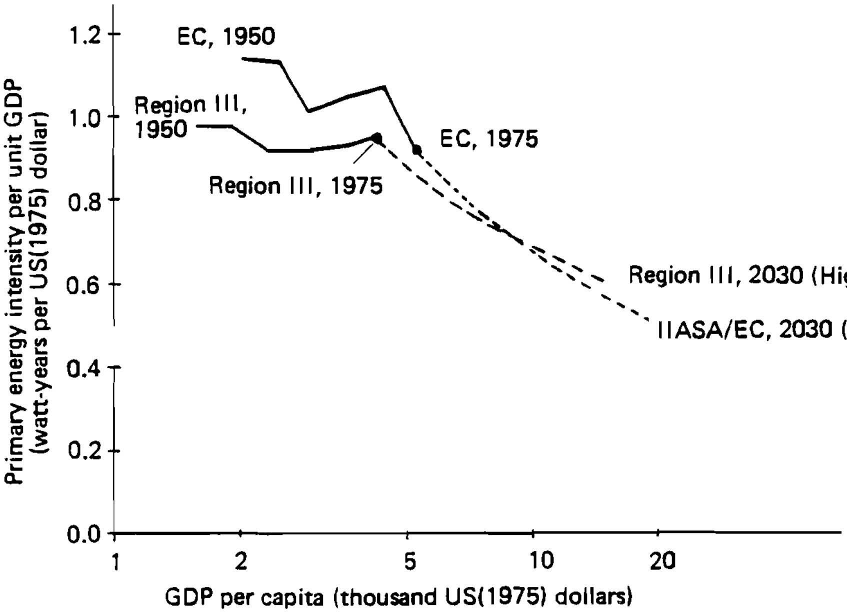

FIGURE 3.9 Evolution of GDP per capita and primary energy intensity per unit GDP (High Scenarios).

3.1.2 The Evolution of Supply

The disaggregation of the energy supply system of IIASA's Region III into "EC" and "Other Region III" has to retain the general characteristics of the energy supply situation of Region III. In a nutshell, this means that the import dependence of the EC stays high in spite of optimistic assumptions about the indigenous production of primary energy. Owing to the extended availability of "dirty" fossil fuels at the global level, the "fossil era" will extend beyond the year 2030. The disaggregation of IIASA's Region III in terms of input data for MESSAGE, together with the input data for the IIASA/EC High and Low Scenarios, is described in the Appendix.

Before the IIASA/EC supply scenarios are specified here in more detail, two points concerning the scenario results for Region III and affecting the solution of the MESSAGE model for the EC subregion will be discussed. The first point is that the projections of indigenous oil supply in Region III were based on early and optimistic assumptions. This means that indigenous oil production figures for the period immediately following the reference year 1975 are too high, and import requirements now calculated are consequently too low for the early time periods of the IIASA/EC scenarios. The second point is that no interregional trade in natural uranium was contemplated in the IIASA scenarios. Rather, a so-called "area approach" was adopted. In this approach, the potential uranium reserves of each region in proportion to the total land area of each of the seven IIASA regions were determined. The specific uranium content per unit area was calibrated against Region I (North America), which is the best explored of the IIASA world regions. This uranium estimation method yields for the EC a total of 770,000 tons of uranium available at a cost of up to US(1975)$50 per pound. Since this amount falls short of the actual EC demand, the most obvious adjustment would have been to assume intraregional trade of natural uranium between the EC and the "rest of the region". In view of the uncertain future of global uranium markets, two extreme cases have been considered: (1) adequate indigenous reserves of uranium to meet any requirements in MESSAGE; and (2) no indigenous supply of uranium whatsoever. Accordingly, in this section two numbers are given in each case for the dependence of the EC on energy imports. The first is the import dependence assuming totally indigenous supply of natural uranium; the second (in parentheses) is the import dependence under the assumption that all the uranium used in the model is imported.

The dependence on imports as well as the description of the IIASA/EC scenarios in terms of the tentative policy goals as described in *Crucial Choices for the Energy Transition* (Commission of the European Communities 1980) are contained in Table 3.12. Case IIa (the Acceptable Dependence Case) of *Crucial Choices* is shown for comparison.

TABLE 3.12 Compliance of scenarios with tentative policy goals.

	IIASA/EC High	IIASA/EC Low	Acceptable Dependence Case
Primary energy in 2030 (per cent)			
Coal	28	15	21
Oil	15	29	29
Gas	16	15	13
Nuclear	37	36	28
Renewables	5	6	10
Import dependence (per cent)[a]			
2000	36(52)	37(48)	66
2030	32(40)	39(43)	45

[a] The first figure shows the import dependence assuming totally indigenous supply of natural uranium; the second (in parentheses) is the import dependence under the assumption that all the uranium used in the model is imported.

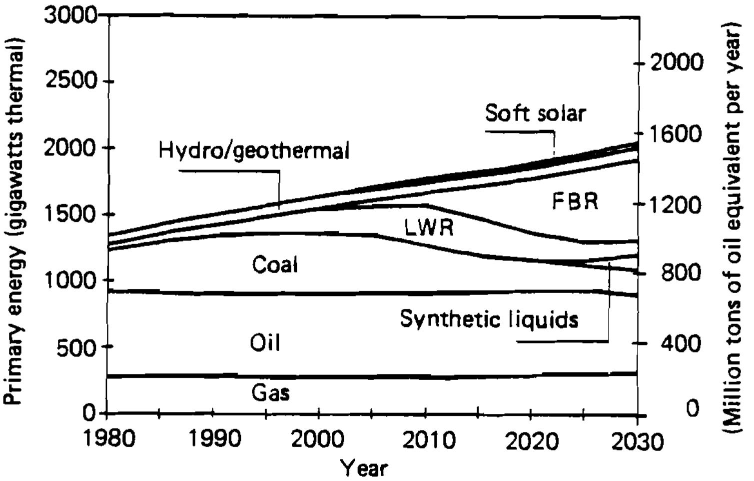

FIGURE 3.10 Primary energy supply, IIASA/EC Low Scenario. FBR, fast breeder reactor; LWR, light water reactor.

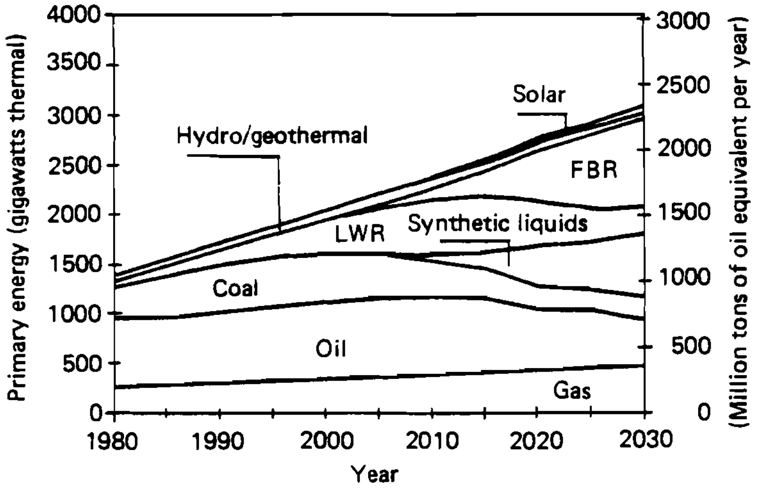

FIGURE 3.11 Primary energy supply, IIASA/EC High Scenario. FBR, fast breeder reactor; LWR, light water reactor.

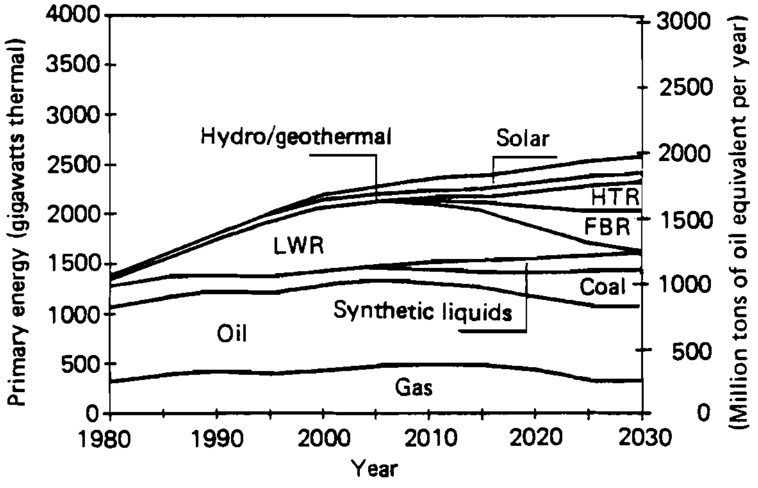

FIGURE 3.12 Primary energy supply, EC *Crucial Choices* Case IIa. FBR, fast breeder reactor, LWR, light water reactor; HTR, high temperature reactor.

With the exception of the nuclear share in total primary energy, the IIASA/EC scenarios meet the tentative policy goals: firstly, an import dependence in the year 2030 of less than 50%; secondly, a dependence of no more than 30% on any single fuel. The absolute quantities behind these relative figures are shown in Figures 3.10–3.12, the primary energy supply. The total primary energy supply of the Acceptable Dependence Case of *Crucial Choices* falls about halfway between the IIASA/EC High and Low Scenarios. However, this statement only applies for the end of the model study period. In the early time periods the primary energy requirements in the EC Case IIa grow even faster than those in the IIASA/EC High Scenario, which in turn outgrow the Case IIa primary energy supply around the year 2010. The reason for this change is the rather drastic decline in economic growth in Case IIa after the year 2000 necessitated by the policy constraints described in *Crucial Choices*. In contrast, the IIASA/EC scenarios exhibit steadier growth at the expense of violating the policy constraints. The differences between the scenarios with regard to the contribution of each fuel type are explained in the following.

Oil

Owing to optimistic estimates of the potential for the fast development of oil production within Region III, the allocations for indigenous oil supply in the IIASA/EC scenarios are rather high. The import quantities are accordingly lower (Figures 3.13–3.15). Toward the fifty-year time horizon, the strain on indigenous oil production will be significantly higher in the High than in the Low Scenario (i.e. oil in cost category II (see Appendix) is only marginally extracted in the Low Scenario). Furthermore, the cumulative availability of oil imports in the IIASA/EC scenarios is higher in the Low Scenario, since the reduced energy demand of other world regions will considerably cut back oil imports there. In contrast to the IIASA/EC allocations, the EC scenarios have corrected downward

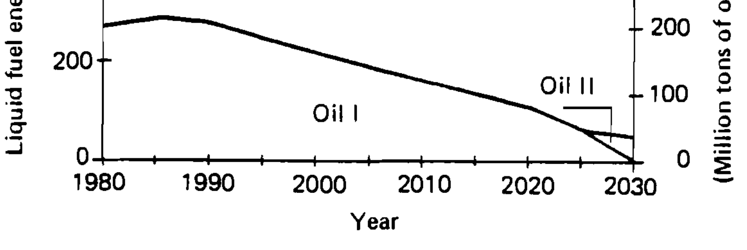

FIGURE 3.13 Liquid fuel supply, IIASA/EC Low Scenario. (See Appendix for oil cost categories.)

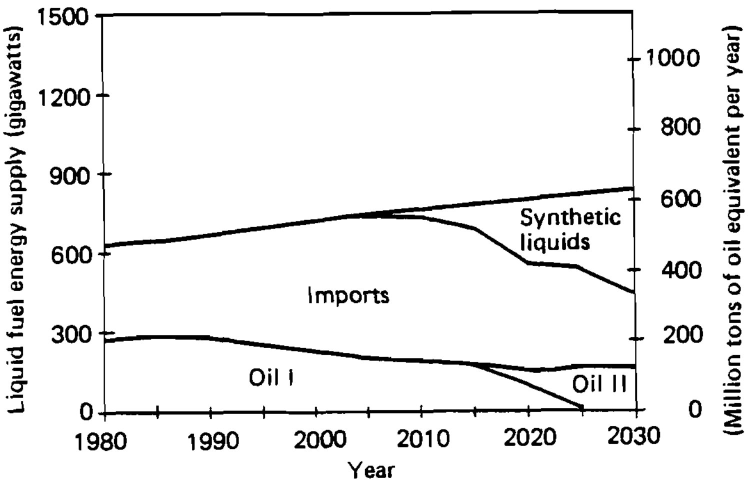

FIGURE 3.14 Liquid fuel supply, IIASA/EC High Scenario.

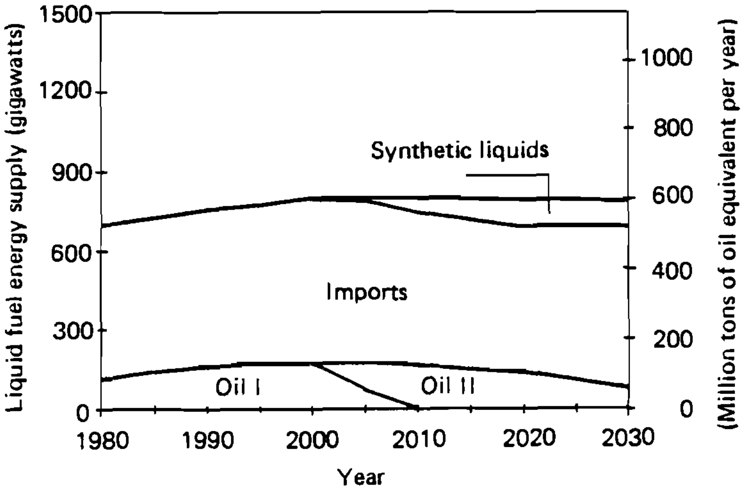

FIGURE 3.15 Liquid fuel supply, EC *Crucial Choices* Case IIa.

the build-up rates for indigenous oil production. The Acceptable Dependence Case (IIa) does not fully use all the oil globally produced in the IIASA Low Scenario owing to policy variables that limit the dependence of the EC on oil imports. In comparing IIASA/EC with EC scenarios, here with Case IIa, it also must be kept in mind that there are differences in the definitions of cost categories.

Synthetic Liquid Fuels

In none of the scenarios considered here can the demand for liquid fuels be met by crude oil products alone. Coal liquefaction technology was therefore included in the supply scenarios. The technical process was not specified in detail; the key assumption was that of an autothermal process (i.e. a technique in which all energy inputs are in the form of coal; this is in contrast to an allothermal technique, which uses process heat from other sources for the synthesis) with a conversion efficiency of 60%, at a cost slightly higher than US(1975)$20 per barrel of crude oil equivalent, and that will be available from the year 2000 onward. In the IIASA/EC scenarios these costs make synthetic liquids slightly more expensive than those derived from imported crude oil. In the IIASA/EC High Scenario synthetic liquids amount to an equivalent of 300 million tons of oil (Mtoe) in the year 2030, thus contributing 47% to the supply of liquid fuels. For the other two scenarios (IIASA/EC Low and the Acceptable Dependence Case) the corresponding numbers are 73 (53) Mtoe, corresponding to 11 (12)% of total liquid fuel demand.

Natural Gas

The common feature of the scenarios considered in this section is that gas imports into the EC are rising quite sharply, even in the IIASA/EC Low Scenario (see Figures 3.16–3.18). In the global IIASA runs, these imports come from the Soviet Union and Eastern Europe. As in the case of oil, the greater availability of natural gas imports in the Low Scenarios is made use of to relax the strain on indigenous production requirements. In Case IIa, the high temperature reactor (HTR) supplies large quantities of gaseous fuels (producing only marginal amounts of electricity as a byproduct). In the IIASA/EC scenarios the HTR is not considered explicitly because in these the label FBR (fast breeder reactor) is intended to include all advanced reactors, which is to be interpreted as reactors

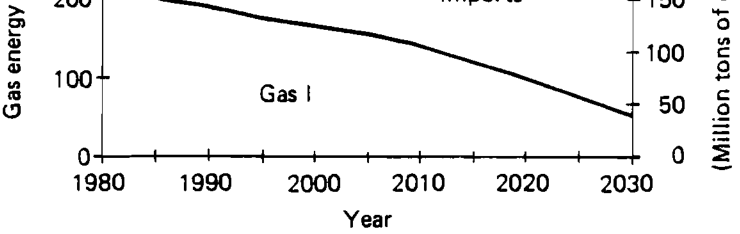

FIGURE 3.16 Gas supply, IIASA/EC Low Scenario. (See Appendix for gas cost categories.)

that make much more efficient use of enriched uranium. Although these advanced reactors quite quickly replace the conventional reactors (labeled LWR) consuming enriched uranium, the consumption of enriched uranium nearly exhausts the EC's estimated ultimately recoverable uranium resources in the IIASA/EC scenarios. This emphasizes the importance of the thorium cycle in advanced reactors.

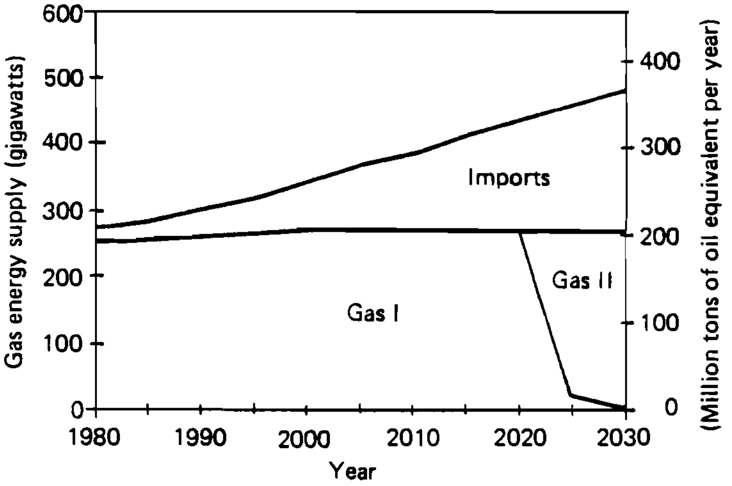

FIGURE 3.17 Gas supply, IIASA/EC High Scenario.

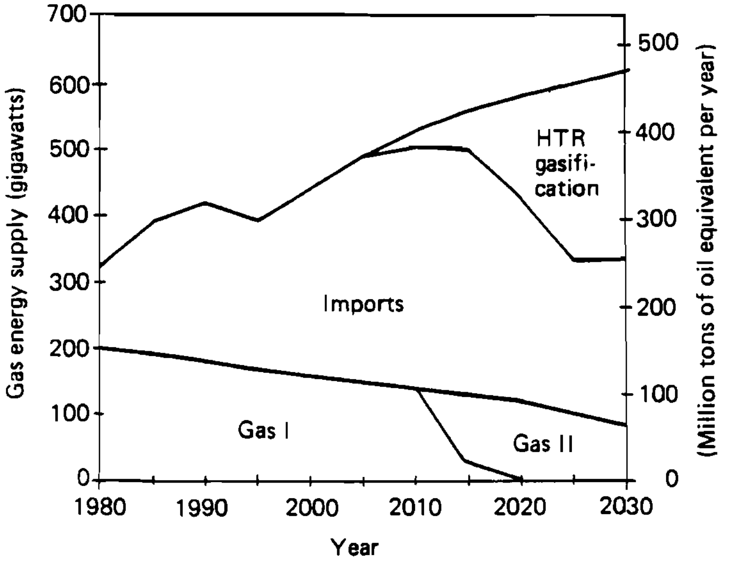

FIGURE 3.18 Gas supply, *Crucial Choices* Case IIa. HTR, high temperature reactor.

Coal

The significant feature in the curves for coal use (Figures 3.19–3.21) is the double peak that occurs in all the scenarios shown. This double peak reflects the two different uses of coal in the scenarios. Initially more coal is needed for electricity generation, but also, in the long term, coal serves as the carbon input in producing synthetic fuels. A decline and subsequent new rise in coal production and consumption may be economically and technically undesirable. This suggests the investigation of an EC Coal Scenario (see Section 4) which would be characterized by steadier growth in coal consumption together with slower growth in nuclear energy supply.

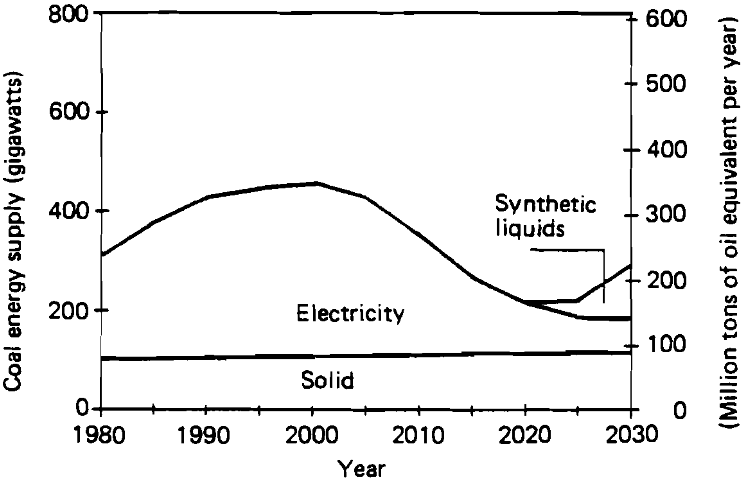

FIGURE 3.19 Uses of coal, IIASA/EC Low Scenario.

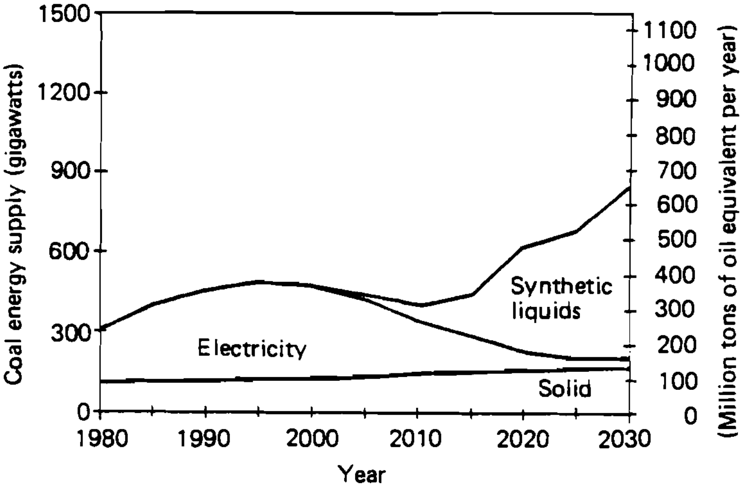

FIGURE 3.20 Uses of coal, IIASA/EC High Scenario.

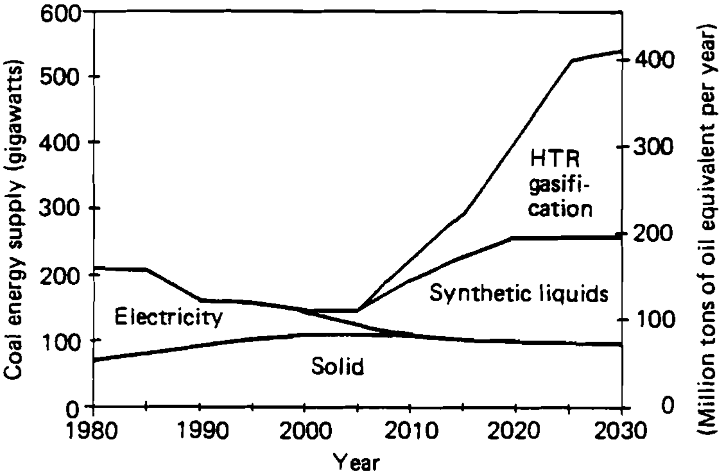

FIGURE 3.21 Uses of coal, EC *Crucial Choices* Case IIa. HTR, high temperature reactor.

Renewable Energy Sources

The contributions of renewable energy sources (other than hydropower and geothermal energy, which are considered separately) in the IIASA/EC scenarios in the year 2030 are 5% (High Scenario) and 6% (Low Scenario). These percentages are in striking contrast with Case IIa, in which the corresponding figure is 10%. The high 10% contribution from renewable soft energy forms had been normatively introduced in *Crucial Choices*, in disregard of prohibitive cost estimates.

3.2 Discrepancies between the Global and the EC Perspectives

The five scenarios presented in *Crucial Choices* were derived on the basis of the methodology shown in Figure 2.3, which is itself a modification of Figure 2.1. The driving inputs to the model loop, as in the global IIASA scenarios, were the assumed growth rates of population and economic activity. Unlike in the IIASA study, the decision criteria in *Crucial Choices* for accepting or rejecting a scenario were based on "energy import dependence" and "technological preferences". In order to cross-check the impact of each energy supply strategy on the economic environment in the EC scenarios implied by the demand calculations, the macroeconomic growth model MACRO was used. This model monitors changes in macroeconomic parameters such as investment rates, capital–output ratios, labor inputs, or energy–GDP elasticities in accordance with historically observed evolutions and/or given (or anticipated) normative changes. The MACRO version implemented for the *Crucial Choices* analysis contained two distinct blocks: a production module of the neoclassical type with capital and labor as the factors of production, and a quasi-Keynesian final demand block determining the aggregate levels of private consumption, gross fixed capital formation, exports, and imports. The adaptation of MACRO to the job of cross-checking energy strategies was achieved by introducing into this model energy import requirements, energy import prices, and specific capital requirements of the energy production sector. Straightforwardly applying such a growth model to monitor the effect on the economy of a changing energy sector – as was done for the *Crucial Choices* scenarios – has certain disadvantages: this method cannot trace indirect feedback effects of rising energy prices on overall economic development; nor can the consistency between energy supply and energy demand levels at given energy prices be investigated. Furthering the strong energy conservation effects and the resulting low elasticities, detailed in Figure 8 of *Crucial Choices*, suggested just such feedbacks and inconsistencies in price effects. The shortcomings of the original MACRO model prompted the development of an improved version of MACRO, described in Rogner (1982).

In the new MACRO version, energy is introduced as a factor of production in the aggregate production function. The macroeconomic demand and supply of all three production factors – capital, labor, and energy – is balanced by way of their respective market prices, in accordance with the underlying production function.

Applying the new MACRO model to the *Crucial Choices* scenarios revealed, in the case of the Acceptable Dependence Case (Case IIa), some serious inconsistencies, which are illustrated in Figure 3.22. On the basis of the energy demand evolution in the Acceptable Dependence Case (bottom curve) the equilibrium energy price should have followed the top broken curve. Instead, the price development actually according to MESSAGE is indicated by the lower broken curve. These discrepancies can be interpreted in the following way: the overall energy conservation effects assumed in MEDEE are not consistent with the price level of energy on the supply side calculated by MESSAGE. This price level would correspond to the expansion in energy demand indicated by the upper solid curve

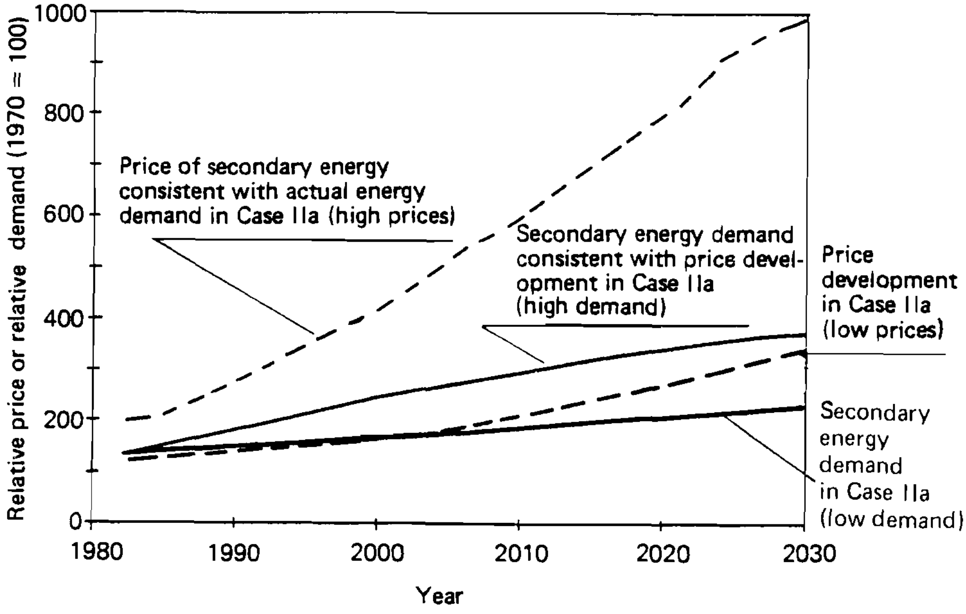

FIGURE 3.22 The inconsistencies in Case IIa. The low price is inconsistent with the low demand.

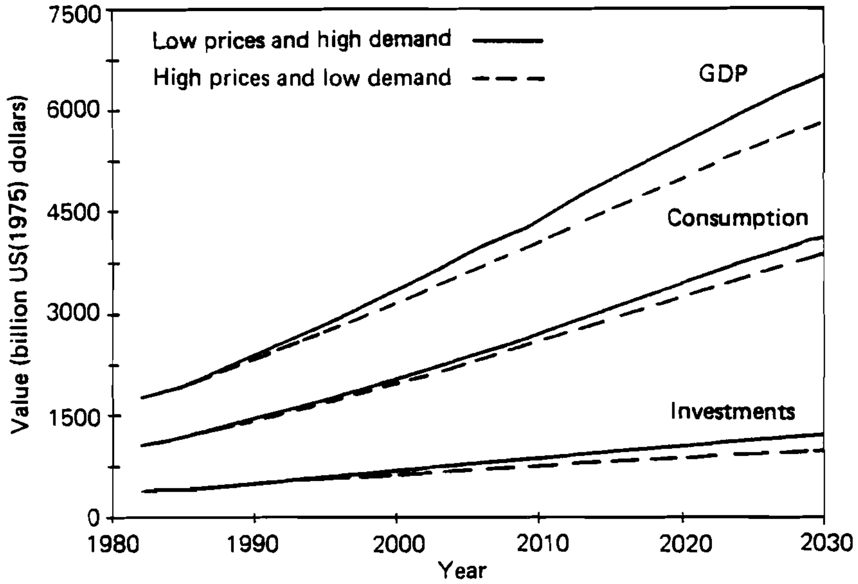

FIGURE 3.23 Impacts on the components of aggregate demand (GDP) of the two consistent cases in Figure 3.22.

in Figure 3.22. Starting from a level of energy demand and energy prices calculated in the *Crucial Choices* scenarios, the new MACRO model produced notable deviations in the evolution of the gross domestic product. More abundant and cheaper energy, of course, allowed for higher economic growth rates than a lesser and costlier energy supply (everything else kept constant). Figure 3.23 illustrates the differences in the expansion of GDP for the two consistent cases shown in Figure 3.22.

The inconsistencies revealed by the MACRO test between energy price evolutions and GDP or energy consumption evolutions basically reflect an inconsistency in the two sets of variables governing the projections of MEDEE and MESSAGE. The projected behavior of energy consumers utilizing energy to produce and consume GDP (i.e. what MEDEE simulates with the help of technological projections) does not match economically with the conditions under which this set of consumers can be supplied with energy (i.e. the macroeconomically optimal allocation of resources and supply technologies in MESSAGE). Quantitatively this inconsistency cannot be resolved by ruling out the *Crucial Choices* scenarios and preferring instead one or both of the IIASA/EC scenarios described in section 3.1. In order to see this, one might compare the GDP evolutions of the Acceptable Dependence Case (Case IIa) with those of the IIASA/EC High Scenario. The latter yields substantially lower GDP evolutions than the former. In line with the findings shown in Figures 3.22 and 3.23, however, a reduction of GDP in the Acceptable Dependence Case would only result from substantially higher energy costs. In Figure 3.11, the primary energy supply system of the IIASA/EC High Scenario, substantially more energy is allocated to the EC economy than in Figure 3.12, the Acceptable Dependence Case energy system. At least for the period up to 2010, though, the average energy cost level does not differ substantially between Figures 3.11 and 3.12 owing to the similar supply pattern of the alternative sources. Thus, within the MACRO logic, the GDP evolution of the IIASA/EC High Scenario comes closer to being consistent with the energy demand evolution. Although the energy price still seems far too low, macroeconomically speaking, one can conclude that there is not enough incentive to bring about the projected level of energy conservation implied by the *Crucial Choices* and the IIASA/EC Scenarios. In fact, the energy cost/energy utility inconsistencies outlined lead to the central question of the extent to which the energy problem will impede an otherwise feasible economic evolution. This prompts the corollary question of whether the energy sector should not be isolated from the rest of the economy and stabilized through transfer payments. After all, the technoeconomic scenarios of *Crucial Choices*, as well as the IIASA/EC scenarios, are constrained by the volume of energy imports available. At the same time, the exogenously fixed oil reference price limits exploitation of alternative more expensive indigenous energy sources. Under the "free market" principle for energy, a macroeconomically justified higher energy demand sustaining effective use of capital and labor would lead to higher imports; these are, however, unavailable. Consequently, the scenarios have normatively fixed high conservation rates and, additionally, cutbacks on economic growth. The results of the macroeconomic consistency test in section 3.2 illustrate that energy conservation rates are not justified at the rates of increase in labor productivity that are still considered feasible; basically one could say that conservation and factors supporting GDP growth do not match. Under such circumstances, one would certainly consider financing both energy conservation and indigenous energy supplies by means of transfer payments from the economy, by reinvesting part of the GDP increases realized, thereby supporting the additional energy supply potential required to bring about this GDP increment. Whether such strategies would be appropriate largely depends on the prospects for further labor productivity improvements. In order to explore such a possibility, the use of macroeconomically adapted energy scenarios is indicated. These scenarios primarily have to assess the macroeconomic growth potential, recognizing first the scarcity of labor and capital. The demand for energy and its macroeconomic substitution price result from the productive condition of the economy and can be estimated endogenously. It is obvious that a highly productive economy, because of its growth tendencies, would absorb increasing amounts of energy even at increasing prices. The endogenous evaluation of energy can, but need not necessarily, coincide with the technoeconomic possibilities of adding energy increments on the supply side. It is also obvious that this evaluation and the process of clearing international energy markets would rank energy differently. A modified, restructured iterative approach to the scenario design appeared necessary in the light of these considerations.

4 THE ADAPTED SCENARIO SET FOR THE EC

The economic inconsistencies that emerged between the global and the indigenous technical solutions (quantified in the IIASA/EC scenarios and in the EC scenarios of *Crucial Choices* respectively) suggested a modification of the scenario writing procedure. The envisaged modification reversed the principal line of thought. Previously the analysis started with the specification (in the form of assumptions) of numerous parameters concerning efficiencies, lifestyles, and shifts between economic sectors within the energy demand model MEDEE. In the subsequent energy supply model MESSAGE, similar specifications relating to energy conversion technologies had to be made. The MACRO model finally made use of the aggregate of the assumptions in the form of the MEDEE and MESSAGE output, including discrepancies of the kind discussed in section 3.2. In section 4.1 the new approach is presented. This time the analysis starts with MACRO projecting overall economic expansion by consistently clearing markets for capital, labor, and energy. Labor productivity evolution and labor force participation rates serve as initial inputs in this new scenario writing procedure, which results in an Economic Response Scenario (see section 4.2). MEDEE translates the aggregate expansion of GDP and equilibrium secondary energy demand into sectoral economic activities and final forms of energy (section 4.3), thus arriving at the required efficiency improvements, lifestyles, etc. These parameters then represent an output rather than an input specification. Finally (section 4.4) MESSAGE investigates this Economic Response Scenario with special consideration of the contributions of nuclear energy and coal to the energy supply system of the EC.

4.1 The Economic Productivity Approach *versus* the Energy Demand Approach

The uncertainty of predicted changes in lifestyles and efficiencies and the difficulties in initiating such changes in a market economy have been major handicaps in long-term scenario writing. The new version of MACRO – together with some modifications in the sequence of the models – is a step in the direction of disaggregating the uncertainty of such changes and their consequences. This is not to say that this new design fully resolves the problem of ambiguity, but rather that it adds a new dimension to the analysis and thus limits the range of uncertainty. For example, it has not so far been indicated how and for what reasons energy conservation efforts will or should penetrate into energy consumption. If one assumes price-induced conservation, discrepancies detailed in section 3.2 between the energy demand as calculated by MEDEE and the energy price level given by MESSAGE may occur. With the newly arranged set of models, this kind of inconsistency can essentially be avoided. Furthermore, the new approach has the advantage of using MEDEE to interpret the aggregate equilibrium energy demand of MACRO so as to disaggregate this energy demand into the corresponding structural changes in the main economic sectors and the implications for energy end use with regard to efficiencies, conservation, etc. The methodological approach was modified according to Figure 4.1.

- The set of energy models is headed by MACRO, thus replacing the former scenario assumptions on economic growth rates by internally calculated rates. Instead, the assumed development of labor productivity has become the essential exogenously determined input.
- Energy import quantities and prices were taken from the global IIASA scenarios, as derived from the identification of the EC region within Region III.
- MACRO's output was monitored against the GDP as given by the IIASA/EC Low Scenario. Productivity assumptions in MACRO were modified until the internally generated GDP growth rates matched those of this Economic Response Scenario.

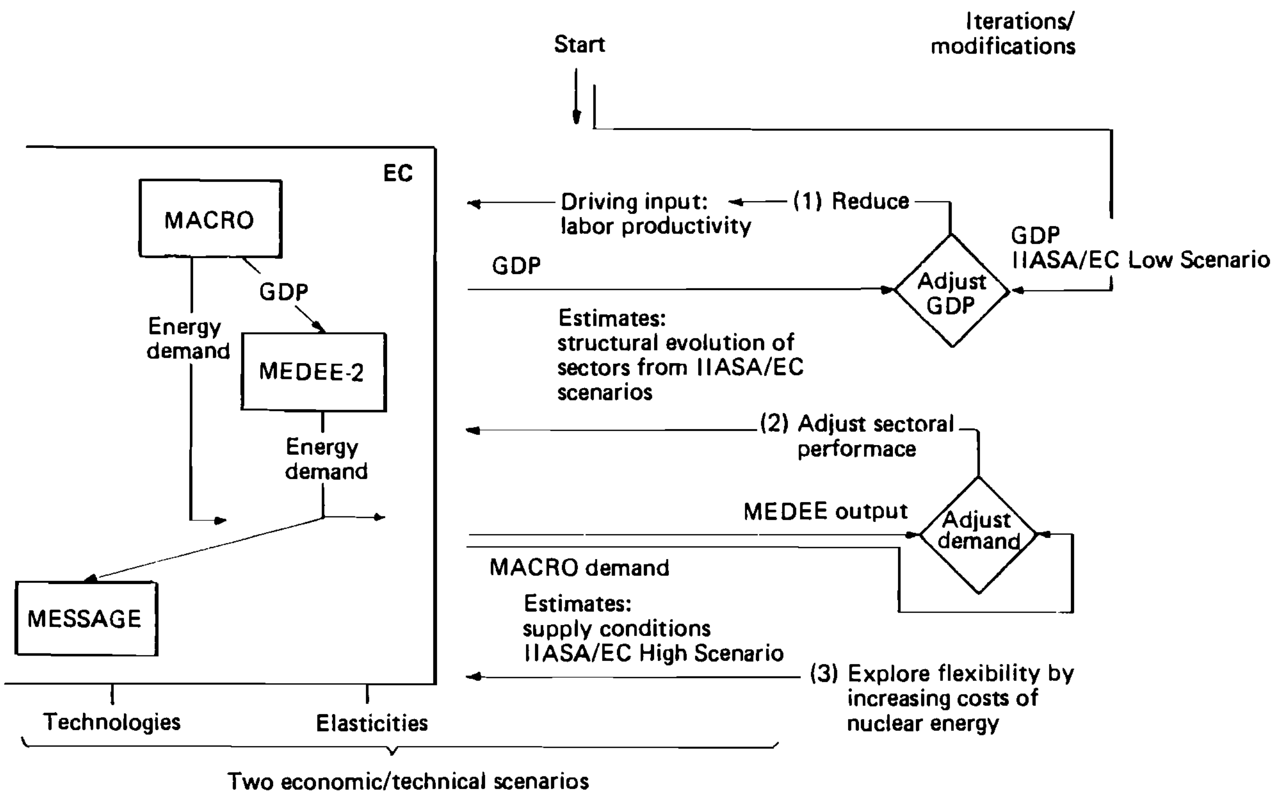

FIGURE 4.1 The process of scenario writing: the macroeconomically derived EC Coal and EC Nuclear Scenarios.

- MEDEE takes the aggregate expansion of GDP and secondary energy demand, estimating the structural evolution of the main economic sectors and the corresponding efficiency improvements and conservation efforts, as well as the final energy demand (quantities and forms of energy).
- MESSAGE calculates the energy supply and conversion activities consistent with the final energy demand of MEDEE and the energy price ceiling provided by MACRO. The possible market penetration of domestic energy supplies together with the reduction of energy imports was the focus of this part of the analysis.
- The loop was closed by feeding energy, capital requirements, and the actual import needs for an energy supply strategy back into MACRO. Thus the flexibility gained by introducing higher prices for the domestic energy supply (in order to increase domestic investment) and alternatively the drain of resources through increased energy imports could be analyzed.

4.2 Macroeconomic Perspectives

In the previous section the revised arrangement of the set of energy models was introduced. The loop in this configuration begins with MACRO, representing an inner loop in its own right. That is to say that before the remaining models MEDEE and MESSAGE were included consecutively in the loop, iterations between MACRO and the main driving inputs or control variables became necessary in order to define a new Reference Case. As already explained in the general outline, the control variable chosen as the most essential in this ongoing analysis was labor productivity. Consequently, new projections of this exogenously determined variable had to be made. In cooperation with the Directorate General XII of the EC Commission, outlooks on the future evolution of labor productivity were identified. Figure 4.2 shows the essential variations of labor productivity compared with Case IIa of *Crucial Choices*. In addition to labor productivity, some of the sociodemographic variables were revised at the same time. The labor force participation rate was assumed to drop to 30% by the year 2030 compared with 35% in Case IIa. Such a reduction in the potential supply of labor reflects the change in the overall age structure of the EC region due to declining population growth rates as well as the effects of anticipated improvements in the welfare system, such as earlier rights to retirement pension, or the tendency to a shorter working week that has been observed during the past decade. All the other exogenously determined variables necessary to run MACRO were transcribed directly from Case IIa, including the remaining discrepancies between energy demand and equilibrium energy prices explained in section 3.2. Two basically controversial developments had therefore to be smoothed out. It must be assumed either that the physical quantity of energy supplied or that the energy price structure in the original analysis for Case IIa is appropriate. In order to evaluate these two paths and eventually to arrive at a synthesis, the following subcases were performed:

(1) The aggregate energy supply was assumed to be identical to that of Case IIa and the corresponding new equilibrium price was calculated.
(2) The equilibrium energy price of Case IIa (see top broken curve in Figure 3.23) was taken and the consistent aggregate energy demand was derived.

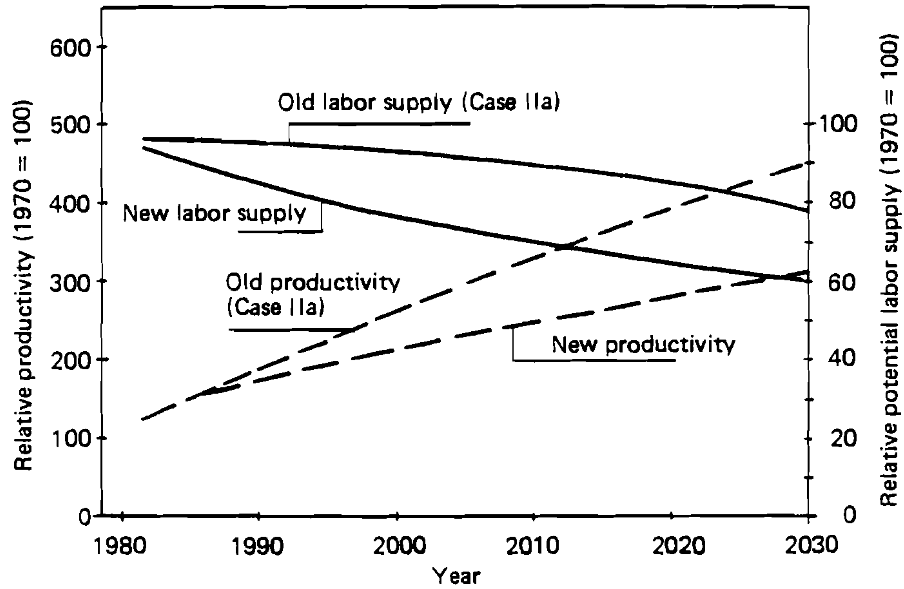

FIGURE 4.2 The change in productivity and labor supply (man-hours per year) assumed in the energy models, in comparison with those for Case IIa.

These two subcases can be summarized as follows: each case was confronted with declining labor productivity growth rates and a drop in the labor participation rate, thus reducing the potential labor input (a quasi-index of productivity multiplied by the potential labor force and the average number of hours worked per week) to roughly 50% of that of Case IIa. A substantial slowdown of economic activity had *a priori* to be expected. In case 1 the burden of the retarded productivity growth is mitigated to some extent by the availability of sufficient energy at prices that hardly differ from today's in real terms. This is easily understood on considering various indicators in Tables 4.1–4.3. For example, the energy intensity remains on a very high level throughout the planning period. The availability of sufficient energy at quasi-constant real prices slows down any substitution process between energy and other factors of production. Thus energy conservation is not a real issue in this case. Economic growth rates, as expected, range considerably lower than in Case IIa, owing to not only the low growth in productivity but also the negative trade balance. Domestic energy production appears to be less expensive than imported energy. However, market penetration constraints restrict the rate of expansion of domestic energy production plants. Therefore 45% of total primary energy still has to be imported by 2030.

In case 2 the higher energy costs have a twofold effect: (1) secondary energy use is cut by roughly 27% compared with Case IIa and (2) the level of GDP is reduced even below that of case 1 (see Table 4.1). The capital–output ratio ranges 5% above the value for case 1 (3.97). This seems to be not too significant, but the picture is somewhat distorted since the major impact on the economy is the reduction in economic activity. If one tries to arrive at a quasi-isoquant (the same economic output as in case 1), the substitution of

TABLE 4.1 GDP growth rates in Case IIa and subcases 1 and 2.

	GDP growth rate (per cent per year)		
	1985–2000	2000–2015	2015–2030
Case IIa	4.0	2.5	1.7
Subcase 1	2.2	1.3	1.2
Subcase 2	2.0	1.1	0.9

TABLE 4.2 Relative energy intensity in Case IIa and subcases 1 and 2.

	Relative energy intensity (1970 = 100)			
	1985	2000	2015	2030
Case IIa	81.5	63.7	53.0	49.5
Subcase 1	88.5	84.5	82.6	75.2
Subcase 2	80.4	70.2	67.2	63.0

TABLE 4.3 Secondary energy prices in subcases 1 and 2.

	Secondary energy prices (US(1975) dollars per ton of coal equivalent)			
	1985	2000	2015	2030
Subcase 1	85.1	102.9	105.4	107.3
Subcase 2	110.9	150.2	178.7	211.5

capital for energy pushes the capital–output ratio to 4.25. The effect on labor is insignificant since labor supply is by definition very tight and limits any substitution possibilities. However, the absolute level of the real wage rate – or labor income – differs by 6% between case 1 and case 2. At this point it becomes necessary to create a synthesis of cases 1 and 2, which is done by taking the average of the energy price growth in cases 1 and 2 (see Figure 4.3). Furthermore, it is normatively assumed that the energy import ceiling and the unit energy import price correspond to those in the IIASA/EC Low Scenario. It takes only a few iterations of the inner loop, using MACRO only and monitoring against the GDP of the IIASA/EC Low Scenario, to arrive at a converging solution for the Economic Response Scenario: that is to say, for economic activity to reach the same absolute value of GDP by the year 2030. Only the growth rates in each period follow a slightly different pattern (see Table 4.4).

The central point of this Economic Response Scenario is to analyze the trade-off between energy imports and investments in the domestic energy production sector, and the impacts on the structural evolution of the main economic sectors. Thus the output of MACRO initiates the iterations of the entire loop including MEDEE and MESSAGE, as shown in Figure 4.1.

The MACRO model is next confronted with two future energy supply paths. One is characterized by very favorable capital costs for the nuclear energy production technologies

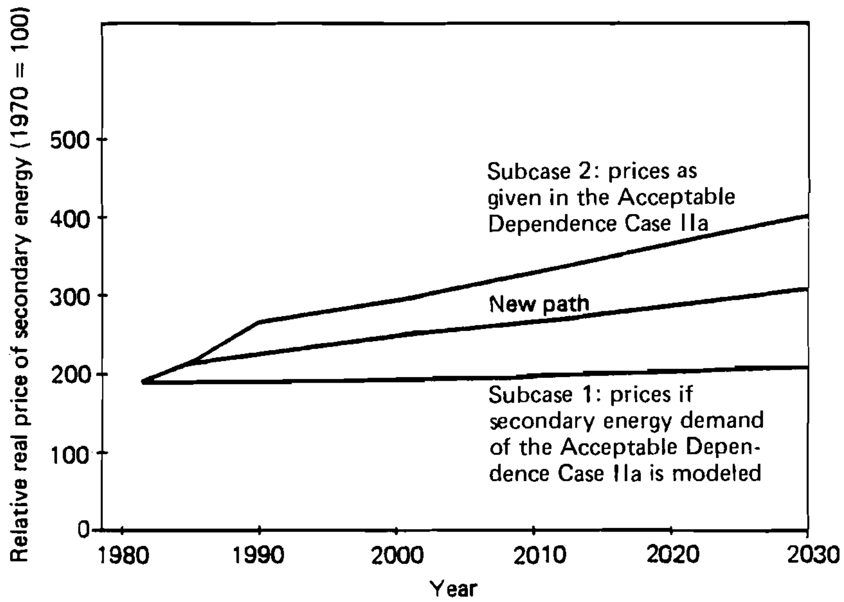

FIGURE 4.3 Energy price growth for subcases 1 and 2 of Case IIa and the average used in the Economic Response Scenario.

TABLE 4.4 Economic indicators in the Economic Response Scenario.

	1985–2000	2000–2015	2015–2030
GDP growth rates (per cent)	2.2	1.2	1.1
Relative energy intensity (1970 = 100)	≈ 83	≈ 74	≈ 70
Secondary energy price (US(1975) dollars per ton of coal equivalent)	83–131	131–140	140–160

(the Nuclear Case), while in the second nuclear energy is considered to fall more in the higher investment categories, thus favoring coal technologies (the Coal Case). The loop – and especially the MESSAGE model – allocates resources quite differently, but the impacts on overall economic development are not significant (see Table 4.5). In the Nuclear Case (favorable nuclear capital costs in MESSAGE) the energy import dependence is reduced to 28% (cf. 45% in Case IIa, 30% in the Economic Response Scenario), allowing the trade balance to remain stable and to range slightly positive. Energy import costs roughly double between 1980 and 2030, which is sufficient time for the economy to adjust appropriately, especially since initial cutbacks in energy imports occur in the 1980s, from about 800 million tons of coal equivalent in 1978 to 625 million tce in 1985.

TABLE 4.5 GDP growth rates in the Economic Response Scenario with favorable and unfavorable nuclear capital costs.

	GDP growth rate (per cent per year)		
	1985–2000	2000–2015	2015–2030
Favorable nuclear capital costs (Nuclear Case)	1.98	1.18	1.11
Unfavorable nuclear capital costs (Coal Case)	1.96	1.12	1.08

When nuclear investment costs are assumed to fall into higher cost categories, the energy import dependence can only be reduced to about 39%, as shown in Figure 4.4(b). The higher energy import quantities, however, push the trade balance into the negative range (see Figure 4.4(a)). This becomes quite apparent around the turn of the century when breeder reactors are delayed owing to cost considerations. The initial trade surplus in Figure 4.4 is due to minor inconsistencies between the MACRO model, based on historically estimated parameters and trends, and the MESSAGE model.

What are the macroeconomic consequences of these two future energy paths? The development of the GDP evolves as expected along a middle-of-the-road path between the subcases 1 and 2 (see Tables 4.1–4.4.) The cumulative difference in GDP amounts to US(1975)$1150 billion, about the amount of the GDP of the EC in 1970. Though small in relative terms considered over a period of fifty years, this difference represents an absolute amount that should not be neglected. The GDP loss may be put into perspective by considering two additional economic indicators: the cumulative loss in the trade balance and the cumulative requirements for capital formation within the energy sector. Over the next five decades US(1975)$930 billion of additional economic output or national income are transferred to the energy-producing countries in the unfavorable nuclear capital cost case. This figure contrasts with the cumulative amount of US(1975)$120 billion in additional investment required in the EC energy sector in the favorable nuclear capital cost case. To put it another way: the increased domestic energy production in the case based on lower specific investment costs for nuclear energy can be sustained with little greater capital accumulation in the energy sector than is required for the high import case with high specific nuclear investment costs. The capital intensity per ton of coal equivalent in production capacity is quite significant: $1360 per tce compared with $1105 per tce in the favorable nuclear capital cost scenarios (the figure for 1970 was $720 per tce). In each scenario, the aggregate energy sector charges against the rest of the economy. Since the difference in the absolute amounts of investment needed in the domestic energy sector appears to be small (but still $120 billion, corresponding to seven times the total investment in energy in 1970)*, any impact on economic development in the unfavorable nuclear capital cost scenario must originate from the greater dependence on energy imports.

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[*] $\Sigma_{1980}^{2030} INV_{\mathrm{E}}$ = $2140 billion in the favorable nuclear capital cost case, compared with $2020 billion in the high import case.

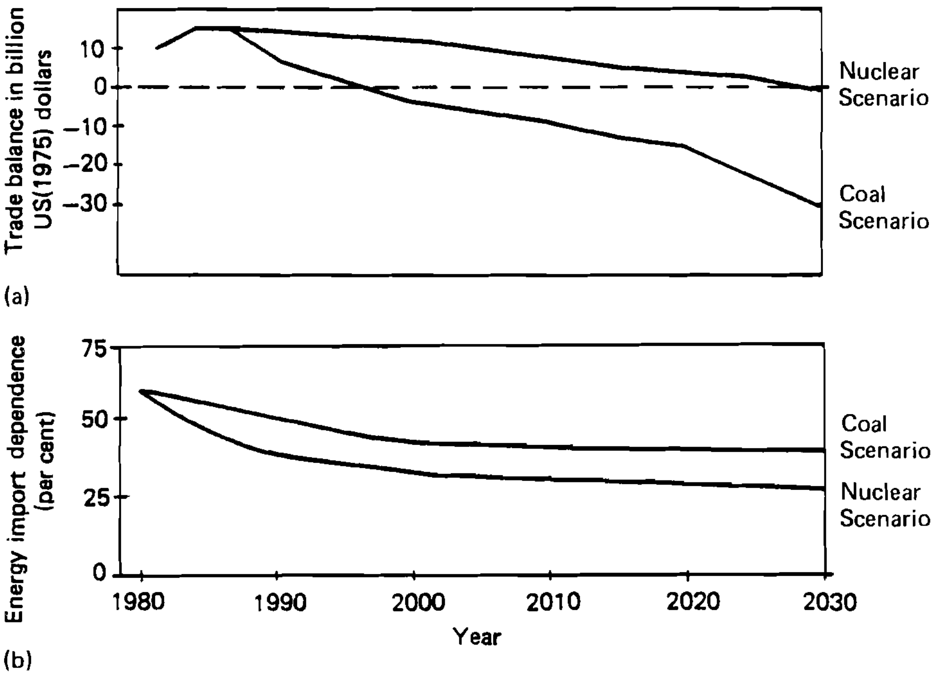

FIGURE 4.4 (a) The effect on the trade balance and (b) the dependence on energy imports in the Coal Scenario and the Nuclear Scenario.

The drain on economic resources over the next 50 years in the high import scenario amounts to $930 billion, causing an accumulated loss in GDP of the order of $1150 billion owing to the increased capital intensiveness of domestic energy needs. The resulting negative trade balance discourages private businesses from investing. The total investment rate drops by one percentage point, from 18.6% to 17.6%. Accumulated, this drop in the investment rate corresponds to $945 billion in total investment, almost exactly the amount of income transferred to the energy-producing countries.

On aggregate, the favorable nuclear capital cost case implies a more capital-intensive economy (owing to the accelerated build-up of an advanced nuclear infrastructure) than in the high nuclear capital cost scenario (the Coal Scenario). The output of the economic-resource- (capital-) consuming energy sector, however, is a high quality product – energy – whose internal economic value has been increased through the permanently increasing prices of the only alternative (apart from conservation and efficiency improvements): imported energy.

Macroeconomically, the model runs indicate that the two responses to a tougher energy supply situation impede economic growth equally, given the assumed energy prices and investment costs. To a first order approximation, neglecting any multiplier and accelerator effects of substituting for imports, it makes little difference whether the same amount of energy is provided via more costly indigenous investments or via increased imports and thus negative trade balances. The very minor deviations in the development of the GDP shown in Table 4.5 seem to support this conclusion.

4.3 A Consistent Energy Demand Structure

Following the approach outlined in section 4.1 and illustrated in Figure 4.1, the next step in this analysis requires the disaggregation of the GDP expansion calculated by MACRO into sectoral activities. The sectoral composition of GDP and its future evolution represent the economic structure and the structural change within an economy respectively. Structural change and the level of economic activity have to be interpreted as the essential driving forces for future energy demand.

The output of MACRO available to MEDEE concerns the absolute level of aggregate demand *GDP* and its components, i.e. private consumption *C*, gross fixed capital formation *INV*, government expenditure for goods and services *G*, exports *X*, and imports *M*. Furthermore, the specific characteristics of the domestic energy sector provide additional information for use in MEDEE, such as value added, investment level, capital stock, and manpower requirements. Finally, according to the modified methodological approach, MACRO's aggregate equilibrium demand for secondary energy must now be translated into sectoral energy conservation efforts, efficiency improvements, etc., by specifying the corresponding final energy demand (forms and quantities).

The Economic Response Scenario, as discussed in section 4.2, provides the quantitative input for the subsequent MEDEE analysis. The GDP grows at the rates shown in Table 4.4. For purposes of comparison, Tables 4.6 and 4.7 present the GDP growth rates of the Economic Response Scenario and the IIASA/EC High and Low Scenarios, together with the projections of other long-term studies. The relative shares of the components of GDP are given in Table 4.8 for the years 1975, 2000, and 2030. The steady drop in GDP growth (to rates far below those observed in the 1950s and 1960s) causes a drop in the investment rate from a level ranging between 20.5% and 23% (1960–1975) to a level of 17.4–18.6% by 2030. The replacement share of investments, however, shows a considerably higher value by the year 2030 of about 78% in the nonenergy sector, compared with

TABLE 4.6 A comparison of GDP growth rates for the EC.

	GDP growth rate (per cent per year)		
Period	IIASA/EC High	IIASA/EC Low	Economic Response Scenario defined by MACRO
1975–1985	3.8	2.8	3.0
1985–2000	3.2	1.9	2.2
2000–2015	2.4	1.4	1.2
2015–2030	1.9	1.2	1.1

TABLE 4.7 Average GDP growth rates (per cent per year) for the period 1975–2000 for the EC compared with growth rates in the *Interfutures* study.

Interfutures		IIASA/EC Scenarios	Economic Response Scenario
High (A)	4.4	High 3.4	2.5
Moderate (B2)	3.3	Low 2.3	
North–South Lift (C)	2.0		
Protectionist (D)	3.0		

TABLE 4.8 Evolution of the components of GDP, 1975–2030, for the EC.

	Percentage of total GDP		
Components of GDP[a]	1975	2000	2030
INV/GDP	20.8	19.6	18.0
C/GDP	62.5	64.2	64.0
G/GDP	14.7	13.4	15.3
X/GDP	25.9	26.9	27.3
M/GDP	23.5	24.1	24.6

[a] *INV*, gross fixed capital formation; *C*, private consumption; *G*, government expenditures for goods and services; *X*, exports; *M* imports.

51% in 1975. In other words, net investment as a percentage of GDP drops from 10.1% to 4%. This reduction in net investment can be interpreted as a shift in economic activity from heavy industries to service-oriented activities. This certainly influences the distribution of value added over the economic sectors in MEDEE, as is shown later. The decline in investment is offset by increased private and public spending, while exports and imports increase to 1.1% and 1.4% greater shares of the total GDP respectively.

Tables 4.4 and 4.8 set the aggregate economic frame for the sectoral disaggregation of economic activities. Since MACRO calculates value added and other parameters of the energy sector, the MACRO output serves as direct input to MEDEE. The absolute level of value added for the energy sector is affected by the degree of energy import dependence. The oil import ceiling in the Economic Response Scenario was taken from the IIASA/EC High Scenario. This choice suggested itself since the aggregate demand for secondary energy fell halfway between the levels in the IIASA/EC High Scenario and the IIASA/EC Low Scenario. The macroeconomic reasons for the high energy intensity of the Economic Response Scenario, which seemingly combines the low economic growth of the IIASA/EC Low Scenario with an energy allocation (aggregate secondary energy consumption) closer to that of the IIASA/EC High Scenario, have been given in section 3.2. As the import ceiling for oil is set very low, the domestic energy sector has to raise its production level accordingly. In the Economic Response Scenario the energy import dependence dropped to about 30% by 2030. The considerably higher domestic energy production increased the share of value added generated by the energy sector from the present figure of about 4% to more than 7%.

The evolution of the GDP shares of all the other economic sectors represented in MEDEE has to be extrapolated on the basis of historical trends and anticipated structural changes, some of which depend directly on the level of aggregate economic growth rates (e.g. the trend to more service-oriented activities and less heavy industry). Between 1960 and 1977, although a relatively short period in comparison with the fifty-year study period, some notable changes in the GDP formation of the EC were observed. According to Table 4.9, the agricultural sector and the construction sector followed a downward trend that was mainly compensated by the augmented shares of industry and trade. In the light of retarded investment rates and productivity growth rates and the declining labor force participation rate, the shifts in the generation of GDP were assumed to be as shown in Table 4.10.

TABLE 4.9 GDP contribution of the EC's main economic sectors (per cent), 1960–1977 (at constant 1975 prices and exchange rates).

Year	Relative GDP (1975 = 100)	Relative GDP per capita (1975 = 100)	Percentage of GDP by economic sector						
			Agriculture	Industry	*Manufacturing industry*	Construction	Trade	Transportation and communication	Other
1960	55	61	6.5	33.7	*28.5*	8.6	11.6	6.4	33.2
1963	63	68	5.9	34.1	*29.1*	8.8	12.0	6.4	32.8
1965	70	74	5.6	34.6	*30.5*	9.2	12.1	6.4	32.1
1970	88	90	5.1	36.6	*33.1*	8.9	12.4	6.6	30.5
1971	91	93	5.0	36.5	*32.7*	8.9	12.5	6.6	30.5
1972	94	95	4.7	36.4	*32.9*	8.9	12.4	6.7	30.8
1973	100	101	4.8	37.1	*33.5*	8.5	12.4	6.6	30.5
1974	102	102	4.8	36.9	*33.6*	8.1	12.4	6 8	31.0
1975	*100*	*100*	4.7	35.9	*31.8*	7.9	12.4	6.7	32.4
1976	105	105	4.3	36.9	*32.7*	7.5	12.4	6.7	32.1
1977	107	107	4.4	37.6	*32.5*	7.3	12.1	6.7	31.9

Source: United Nations (1978).

A pronounced shift to the service sector at the expense of the mining and manufacturing sector is the most notable assumption. The shares of agriculture and construction continue to decline at historically observed rates. The internal structure of manufacturing shows a reduction in the share of basic materials and a higher contribution from machinery and equipment. This runs counter to past trends toward decreasing shares for the so-called light manufacturing industries (mostly nondurable or semidurable consumer goods) (see Table 4.11). Within manufacturing these declining shares had been offset by faster growth in heavy manufacturing, chemicals, and metal products. The outputs of these subsectors, however, are essentially investment goods. In the light of modest GDP growth rates and

TABLE 4.10 Anticipated shifts in the contributions of the EC's economic sectors to the GDP.

	Percentage contribution to GDP	
Sector	1975	2030
Agriculture	4.7	3.2
Construction	7.9	7.0
Mining and manufacturing	31.8	25.6
Energy	4.1	7.2
Services	51.5	57.0
Manufacturing		
Basic materials	30.0	28.7
Machinery and equipment	37.0	38.3
Nondurables	33.0	33.0

TABLE 4.11 The distribution of the EC's industrial production by sectors, 1960–1977.

	Percentage of total industrial production, by year								
Sector	1960	1963	1968	1970	1973	1974	1975	1976	1977
Relative total industrial production (1970 = 100)	63	71	88	***100***	115	116	108	116	118
Mining/drilling	**6.2**			**4.1**			**3.5**		**3.4**
Coal	5.2			2.3			1.6		1.3
Oil	0.2			0.4			0.6		0.7
Metals	0.2			0.2			0.2		0.1
Manufacturing	**88.5**			**89.3**			**88.1**		**88.2**
Light manufacturing	34.7			30.4			29.8		29.9
Food etc.	*11.0*			*10.0*			*10.6*		*10.0*
Textiles and apparel	*12.0*			*8.6*			*8.1*		*7.6*
Wood products	*3.6*			*3.5*			*3.6*		*3.7*
Paper, printing, and publishing	*5.6*			*5.7*			*5.1*		*5.3*
Heavy manufacturing	55.0			58.9			58.3		58.3
Chemicals, petroleum, etc.	*8.4*			*12.0*			*12.6*		*13.4*
Nonmetals, mining products	*3.8*			*3.8*			*3.7*		*3.7*
Basic metals	*9.0*			*7.9*			*6.8*		*6.6*
Metal products	*34.2*			*35.7*			*36.2*		*35.6*
Electricity, gas, water	**5.3**			**6.6**			**8.4**		**8.4**

the drop in the investment rate, accelerated growth in heavy manufacturing and metal products seems unlikely. On the other hand, the output of light manufacturing will most probably not continue to lose its market share. The increased output of electronics equipment, communications equipment, etc., will reverse this past trend in the decades to come.

After identifying the expansion of various economic sectors and the implications for the structural composition of the GDP, the next step is the evaluation of an energy demand structure consistent with both the composition of the GDP in MEDEE and the equilibrium energy demand provided by MACRO. This requires the specification of energy efficiency improvements, lifestyle changes, penetration rates, and other indicators.

In the wake of low economic growth and reduced investment rates, technical progress, especially improvements in energy efficiency, is likely to remain rather modest. Within the manufacturing sector, the electrical energy intensity is assumed to decrease by 0.17% per year while the improvement in thermal energy intensity amounts to 0.47% annually.

With the further slow trend to electricity in thermal uses (10% above present day levels by 2030), the moderate growth of district heating (11% of steam and hot water by 2030) and soft solar energy (12% of low temperature steam and hot water by 2030), and gradual improvements in the efficiency of fossil fuel use, the final energy intensity in manufacturing industries declines in this scenario by 0.55% per year. This is very low compared with the figures for the period 1960–1976, when the rate of decline was 2.2% per year in the EC, 2.7% per year in the US and in Japan, and 2.2% per year for all OECD countries together. On the other hand, this was a period of high growth (manufacturing value added in the EC grew at a rate of 3.8% annually) compounded with a rapidly changing product mix. In addition, the introduction of new equipment together with the rapid substitution of oil and gas for coal in the past twenty years greatly enhanced the efficiency of energy use in manufacturing. These improvements were not primarily due to special efforts to economize on energy but rather resulted from technical progress in general; the prospects for further improvements seem rather limited given the trend to a stagnant economy with the low investment rates outlined by the MACRO model.

With regard to freight transportation (excluding pipelines), it is assumed that the total number of ton-kilometers will increase by a factor of 2.5 between 1975 and 2030, in parallel with the growth in the value added for nonservice sectors. In the absence of any changes in the modal breakdown or intensity improvements, motor fuel demand for freight transportation increases by the same factor. In fact, a more realistic assumption would be a moderate further shift from railways to road transportation and a reduction in the energy intensities of various modes; the net effect would be that the average energy intensity over all modes of freight transportation would be fairly constant, since the two trends counteract each other. The performance of trucks especially should be expected to improve with increased pressure from fuel prices. But besides vehicle performance, the average energy intensity will be significantly influenced by capacity utilization, traffic conditions, and the proportion of long-distance to short-distance hauls.

Motor fuel consumption for international and military transportation, which was estimated to be approximately 5% of total motor fuel consumption in 1975, increases by a factor of 2.6 between 1975 and 2030 in the Economic Response Scenario, accounting for about 7% of motor fuel consumption in 2030. This end-use category is assumed to grow in parallel with the GDP.

Energy consumption for passenger transportation was estimated to account for about 70% of total motor fuel consumption and about 50% of electricity consumption for transportation in 1975. With motor fuel consumption growing by a factor of 1.9 and electricity for transportation by a factor of nine between 1975 and 2030 in this scenario, passenger transportation would account for 65% of total motor fuel consumption and 76% of electricity consumption for transportation in 2030. The rapid growth in electricity use is mostly due to the assumption that by 2030 about 20% of urban cars will be electric. The underlying assumptions concerning the increase in passenger travel are summarized in Table 4.12.

TABLE 4.12 Assumed increase in EC passenger transportation, 1975–2030.

	1975	2030
Car ownership per 1000 population	270	400
Total passenger-kilometers by car	2×10^{12}	4×10^{12}
Total passenger-kilometers by public transport	0.45×10^{12}	2.2×10^{12}
Plane travel as a percentage of total passenger-kilometers by public transport	6%	18%

TABLE 4.13 Assumed changes in EC energy use in the household and service sector, 1975–2030.

	1975	2030	Percentage change, 1975–2030
Households			
Population	258 million	290 million	+ 12%
Persons per household	3	2.3	
Dwellings	85.8 million	126 million	+ 47%
Useful energy consumption[a]			
Space heating	138 GWyr (77%)	245 GWyr (65%)	
Water heating	19 GWyr (11%)	50 GWyr (13%)	
Cooking	8 GWyr (4%)	12 GWyr (3%)	
Air conditioning	—	3 GWyr (1%)	
Electrical appliances	15 GWyr (8%)	65 GWyr (17%)	
TOTAL	180 GWyr (100%)	375 GWyr (100%)	+ 108%
Consumption per dwelling			
Useful	18,000 kWh	26,000 kWh	
Final	25,000 kWh	32,000 kWh	
Service sector			
Floor area	17.5×10^8 m^2	27.8×10^8 m^2	+ 50%
Useful energy consumption[a]			
Thermal uses	42 GWyr (74%)	57 GWyr (61%)	
Air conditioning	1 GWyr (1%)	5 GWyr (6%)	
Specific electricity requirements	14 GWyr (25%)	31 GWyr (33%)	
TOTAL	57 GWyr (100%)	93 GWyr (100%)	+ 63%
Consumption per 100 m^2			
Useful	28,000 kWh	29,000 kWh	
Final	37,000 kWh	35,000 kWh	

Note: GWyr: gigawatt-year (10^9 watt-years); kWh: kilowatt-hour.
[a] Equivalent electricity requirements.

Reductions in energy intensity are assumed to occur mainly in cars (30% lower in 2030 than in 1975) and in planes (12% lower), but not in other modes of public transport owing to reduced load factors and limited scope for improvements in vehicle performance.

Energy use in dwellings and service sector buildings accounts presently for about 35% of total final energy consumption. In the Economic Response Scenario this share remains almost constant throughout the study period. The detailed assumptions are summarized in Table 4.13.

The increasing demand for space heating results mainly from the assumed shift to central heating (in 2030 in the Low Scenario only 6% of the total housing stock is without central heating, compared with more than 50% in 1975) and from the larger size of new dwellings, which has a greater effect than the reduction of heat loss by 20–25%. The major growth areas, however, are assumed to be electrical appliance use and water heating.

In the service sector, growth in thermal energy use is in parallel with the growth in floor area, assuming that more widespread heating in new buildings offsets energy savings due to improvements in insulation. Again, the major growth item is assumed to be specific electricity requirements.

On comparing again the two cases (IIASA/EC Low Scenario and the Economic Response Scenario) in Figures 4.5 and 4.6, we observe that the differences are mainly in the projections of energy use for transportation and in buildings. This becomes even clearer when we look at the energy intensities of the various sectors, which are summarized in Table 4.14 in order to give an aggregate characterization of each scenario.

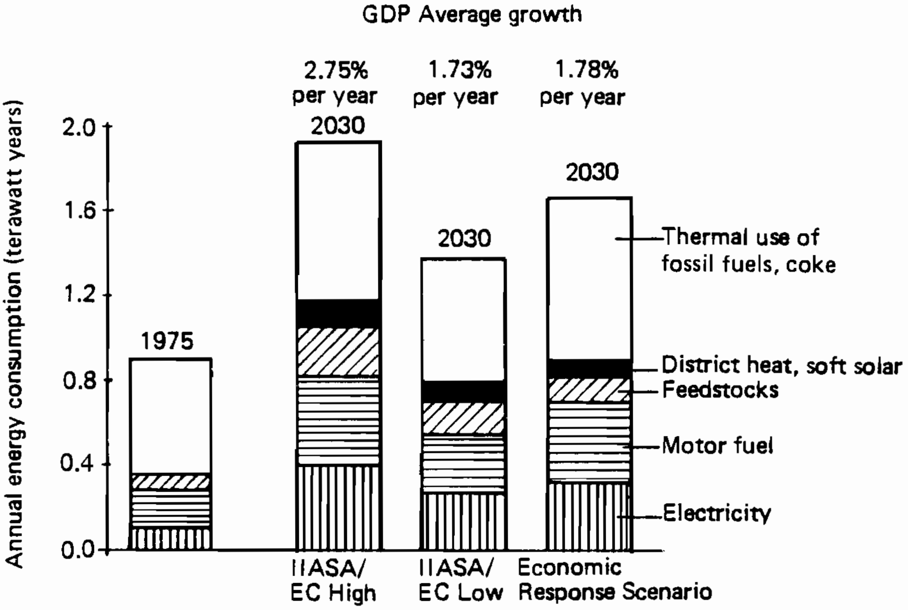

FIGURE 4.5 Projections of the use of energy in the IIASA/EC scenarios and the Economic Response Scenario for 2030, disaggregated by source.

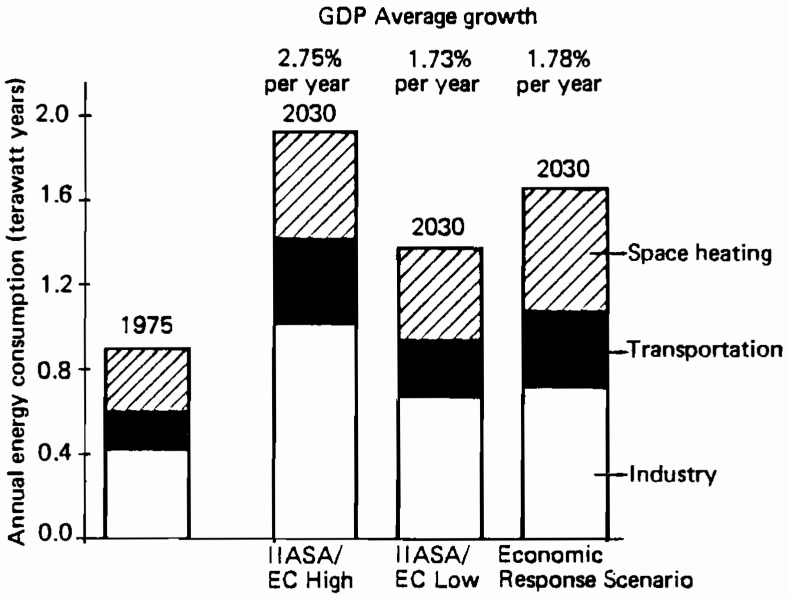

FIGURE 4.6 Projections of the use of energy in the IIASA/EC scenarios and the Economic Response Scenario for 2030, disaggregated by sector.

TABLE 4.14 A comparison of final energy demand statistics for the EC.

		2030		
	1975 (base year)	IIASA/EC		Economic Response Scenario
		High	Low	
Population (millions)	258	304	304	290
GDP per capita (thousand US(1975) dollars)	5.25	19.8	11.5	12.4
Final energy per capita (kilowatts)	3.5	6.4	4.5	5.7
Electricity per capita (kilowatts)	0.4	1.3	0.9	1.1
Final energy per unit GDP (watts per US (1975) dollar)	0.67	0.32	0.40	0.46
Manufacturing				
Final energy per unit value added (watts per US(1975) dollar)	1.00	0.60	0.66	0.74
Freight transportation				
Final energy per ton-kilometer (kilowatt-hours thermal)	0.552	0.438	0.438	0.552
Passenger transportation				
Final energy per passenger-kilometer (kilowatt-hours thermal)	0.424	0.330	0.277	0.335
Households				
Final energy per dwelling (thousand kilowatt-hours)	25.5	26.7	23.6	31.9
Service sector				
Final energy per 100 square meters floor area (thousand kilowatt-hours)	37.2	27.3	24.8	34.6

It should be recalled that the Economic Response Scenario outlined earlier is an *illustration* that indicates what set of detailed assumptions about the evolution of energy demand in various sectors would be "consistent" with the aggregate evolution of the economy in general, and with energy demand and energy prices, as calculated by the MACRO model, in particular. Clearly there can be no unique set of such assumptions; but the foregoing attempt demonstrates how macroeconomically balanced energy use would translate into reasonable sectoral conservation efforts. The conclusions to be drawn are as follows.

- The straightforward technical energy demand projections, based on a consideration of the technical potential for energy conservation and the saturation of certain energy demand categories in the "consumptive" sectors of the economy (passenger transportation, household and service sector), as in the scenarios for Region III and by analogy for the EC, clearly tend to be lower than projections resulting from a macroeconomic model.
- There is a danger in the bottom-up scenario approach, using MEDEE-2 as the initial model in a scenario writing sequence, of accumulating trends in one direction, while in reality these trends could be offset by others that are not anticipated.
- The MACRO model – although it offers the advantage of formal consistency on an aggregate level within the idealization of an equilibrium between energy, capital, and labor – suggests that energy demand is solely affected by the energy price, which may be overstated, since the parameter estimates are based on a relatively short period (1960–1978) in which the aggregate energy elasticity was approximately equal to unity. The energy/output elasticity in industry used to be significantly less than unity and the energy/income elasticity of households significantly greater than unity; this latter figure should decline if saturation effects occur. This deficiency, however, is partially offset by the constant elasticity of substitution production function, where the estimated elasticity of substitution tends to the more optimistic (higher) side. The secondary energy–GDP elasticity for the years 2015–2030 dropped to 0.67, compared with 1.06 for the period 1960–1970.

4.4 Supply Flexibility: Coal *versus* Nuclear Energy

The design of the Economic Response scenario yielded – under the given assumptions quite naturally – a low economic growth scenario. This new scenario provided the opportunity for an investigation of the flexibility in primary energy supply. This flexibility arose when the supply constraints of the IIASA/EC High Scenario were combined with the relatively low demand figures that were specified in detail by the new MEDEE-2 runs. The wider choice that resulted from this combination was explored by describing two supply alternatives: a Coal Scenario and a Nuclear Scenario.

Both supply scenarios (Nuclear and Coal), viewed from the input side of the energy supply model MESSAGE, are most significantly characterized by the reduction of total secondary energy demand in 2030 by 16% from the level in the IIASA/EC High Scenario, which was based on a disaggregation of IIASA's High Scenario for world Region III (OECD countries excluding North America).

A comparison with the Acceptable Dependence Case – Case IIa in *Crucial Choices* – shows that total secondary energy demand in the Economic Response Scenario is 7% lower in 2030. For the year 2000 the same comparison shows a level 17% lower for the Economic Response Scenario. These remarkable differences at two points of time indicate that the Acceptable Dependence Case combined high growth in the earlier period (reflecting the high economic growth desired politically) with a precipitous decline in growth rates after the year 2000 (induced by taking into consideration long-term policy goals). Characterized in similar terms, the alternative supply scenarios (Coal, Nuclear, and Economic Response Scenarios) try to combine these two aspects (growth aspirations and policy goals) throughout the time horizon.

The assumptions on energy supply constraints in the Nuclear Scenario and the Coal Scenario remained basically unchanged from those in the IIASA/EC High Scenario (see the description of the data in the Appendix). The only difference is the adjustment of the oil supply constraints. The maxima for indigenous oil production, which had been based on early and very optimistic assumptions on IIASA's part, were reduced to more realistic levels for the first twenty-five years of the time horizon. Accordingly, the constraints for oil imports were relaxed to compensate for the reduction in indigenous supply.

Reducing demand while maintaining supply opportunities naturally broadens the choice of energy supply strategies. This is clearly demonstrated by the coal balance of the Nuclear Scenario (Figure 4.7). This figure shows a substantial drop in total coal consumption around 2000 to 2010, indicating the potential for additional supply. It also demonstrates the double role coal plays in the future energy supply: its near-term role is increasingly to provide the input for electricity generation until enough nuclear capacity is available to meet electricity demand (Figure 4.8). The second, long-term role is to provide the raw material for the production of synthetic liquid fuels which increasingly replace imports of crude oil (Figure 4.9).

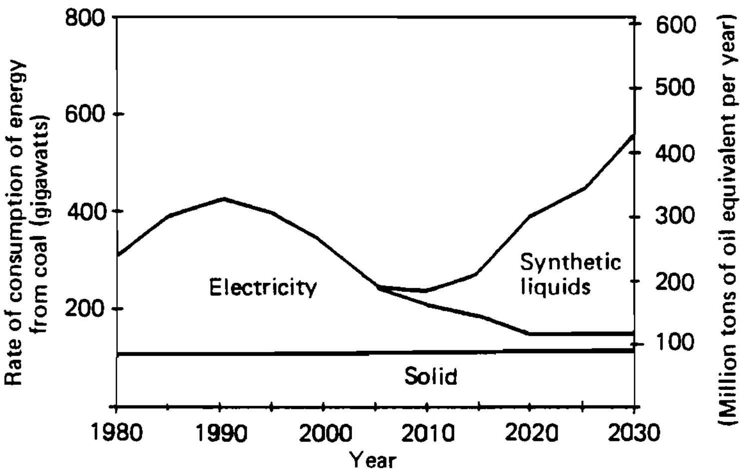

FIGURE 4.7 EC coal use in the Nuclear Case.

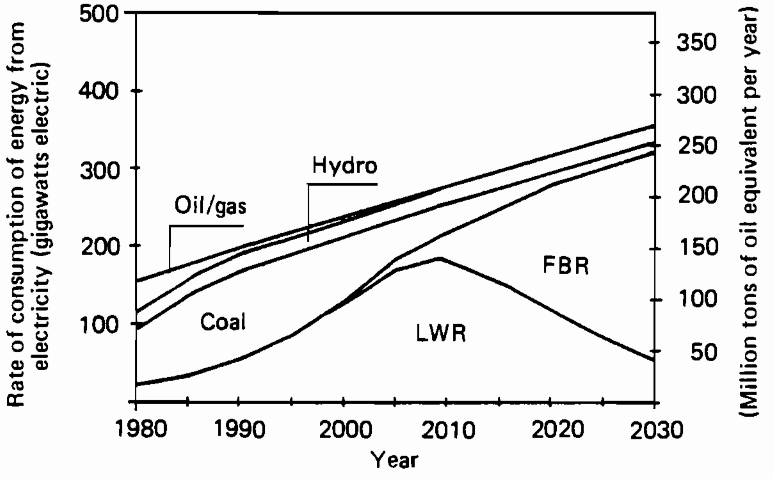

FIGURE 4.8 EC electricity generation in the Nuclear Case.

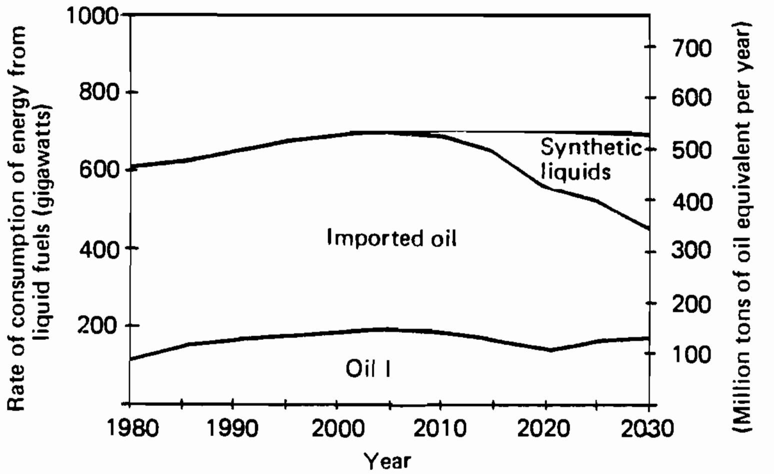

FIGURE 4.9 EC liquid fuel supply in the Nuclear Case. (See Appendix for cost categories.)

The great unexploited potential for coal supply in the Nuclear Scenario led to the formulation of an alternative scenario in which coal, assumed to be abundant, was used more widely, to allow a more limited introduction of nuclear power and in particular a delay in the deployment of advanced reactors. The means of achieving this delay in the supply scenario was a doubling of capital requirements for the installation of nuclear power plants, which reversed the positions of coal and nuclear power in the preference ranking established by the supply model on the basis of cost figures. Figures 4.10–4.12 show the results of the Coal Scenario. According to these figures nuclear energy plays the role of a "stand-by" energy carrier filling the gap that remains between electricity supply and demand after coal is used to meet direct demands, i.e. for replacing crude oil imports and for generating electricity. The introduction of advanced nuclear reactors is accordingly delayed beyond the model's planning horizon.

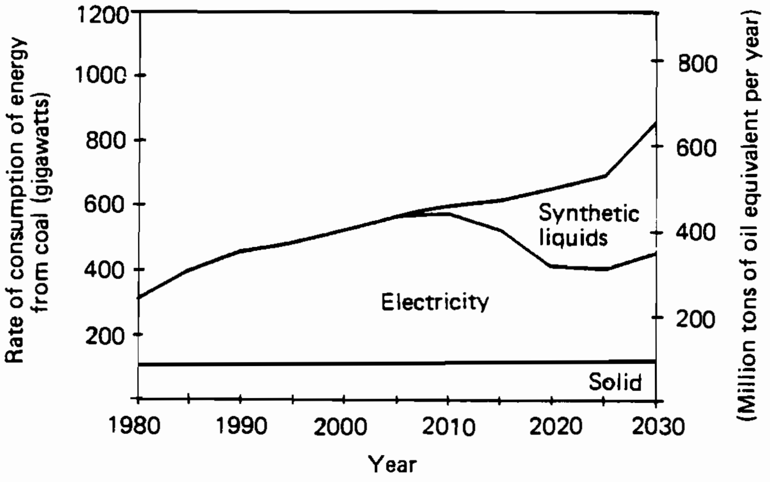

FIGURE 4.10 EC coal use in the Coal Case.

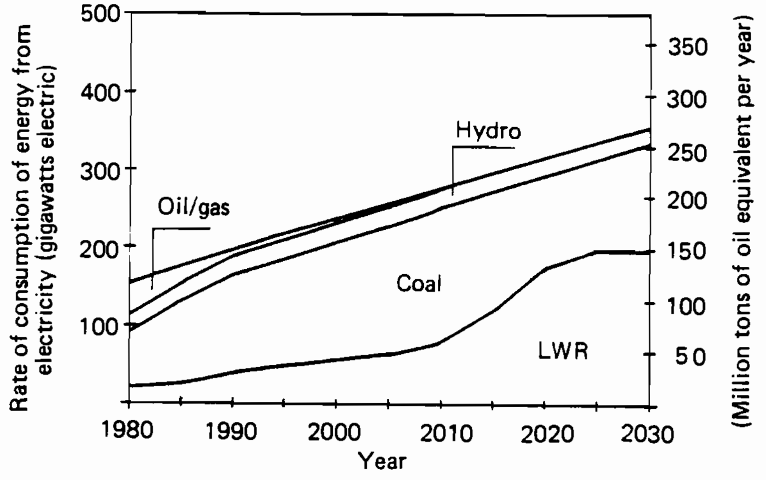

FIGURE 4.11 EC electricity generation in the Coal Case.

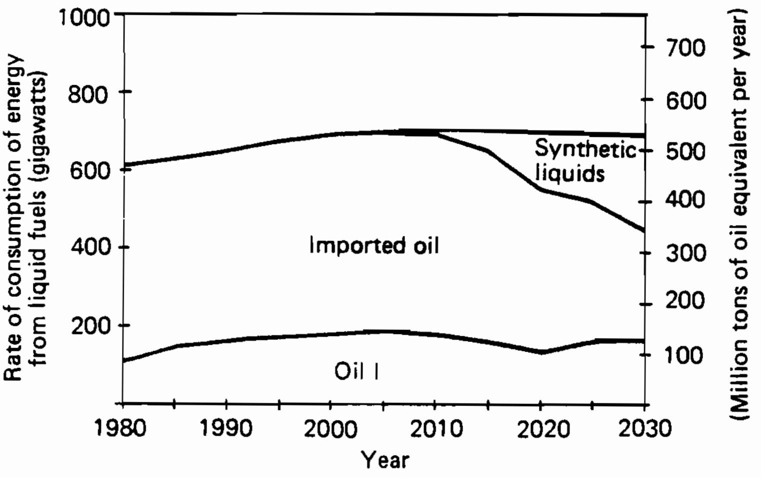

FIGURE 4.12 EC liquid fuel supply in the Coal Case. (See Appendix for cost categories.)

The essential differences between the Coal Scenario and the Nuclear Scenario with respect to the consumption of natural uranium are presented in Figures 4.13 and 4.14. Contrary to what might have been expected, the consumption of natural uranium is slightly higher in the Coal Scenario than in the Nuclear Scenario. The reason for this is the delay in commissioning fast breeder reactors and the consequent higher utilization of light water reactors. The categories of uranium underlying these figures refer to the two cost categories US(1975)$30 per pound of U_3O_8 ($80 per kilogram of uranium) and $50 per pound of U_3O_8 ($130 per kilogram of uranium). In the IIASA/EC High Scenario no imports of uranium are projected in view of the so-called area approach in the IIASA scenarios (see the description in section 3.1).

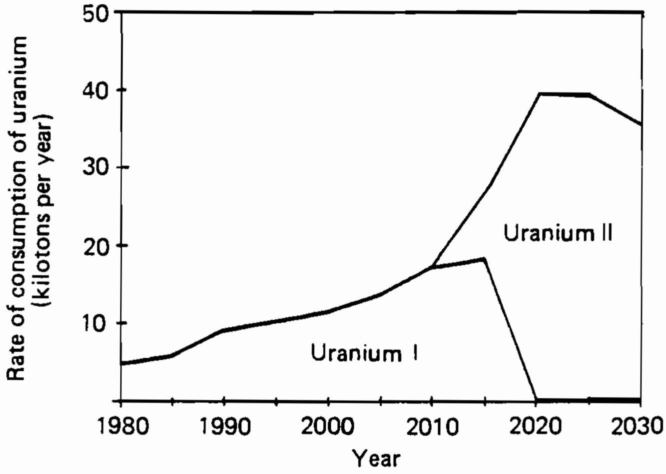

FIGURE 4.13 EC use of natural uranium in the Coal Case. (See Appendix for cost categories.)

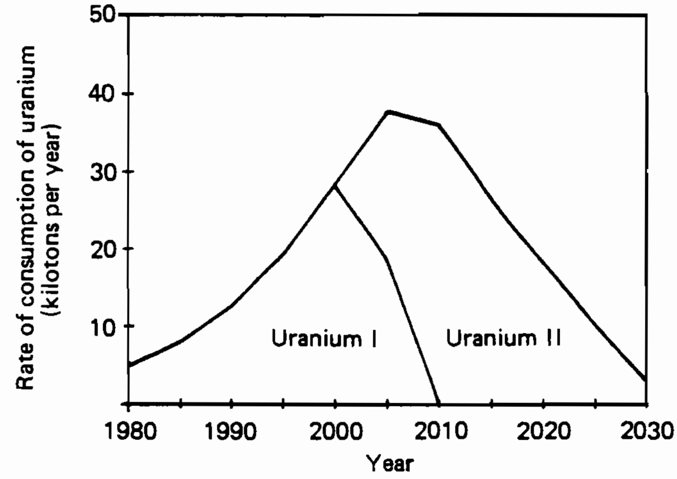

FIGURE 4.14 EC use of natural uranium in the Nuclear Case. (See Appendix for cost categories.)

An evaluation of the two supply scenarios in terms of the tentative policy goals (to maintain upper limits on import dependence and to limit the dependence on any single primary energy source) described in *Crucial Choices* is shown in Table 4.15. Because of the unspecified origin of the supply of natural uranium (imported or indigenously produced), Table 4.15 contains two figures for the import dependence in 2030. For the lower figure it is assumed that all natural uranium in 2030 is indigenously produced, and for the higher that all the uranium consumed in this year is imported. This clearly affirms the important role to be played by advanced reactors if energy self-sufficiency becomes a prime policy goal. The other feature of Table 4.15 is the virtually interchanged figures for coal and nuclear energy as primary energy suppliers. These two scenarios can be regarded as two extremes between which the path of future development can be chosen. It must be stressed, however, that for many reasons the actual room for maneuver may be much smaller. In particular, all constraints on primary energy availability have been copied from the IIASA/EC High Scenario – a consistent world energy trade scenario resting on the basic assumption of free cost-dependent access to global energy resources. Developments since 1975 have not vindicated this assumption: countries have limited their oil and gas production in view of their own long-term needs.

TABLE 4.15 Scenario results in comparison with tentative policy goals.

	Primary energy sources in 2030 (per cent)					Import dependence[a] (per cent)	
	Coal	Oil	Gas	Nuclear	Renewables	2000	2030
Coal Case	35	19	20	21	4	42 (50)	40 (61)
Nuclear Case	23	19	20	34	4	32 (51)	28 (33)

[a] For the first figure, all natural uranium consumed is assumed to be indigenously produced; for the figure in parentheses, all natural uranium consumed is assumed to be imported.

On consideration of these two supply scenarios one might form the impression that coal and nuclear energy are the only major alternatives for energy supply over the next fifty years. Although the decision between high coal/low nuclear and low coal/high nuclear is a very important one, requiring commitments and adjustments well in advance of implementation, other alternatives must be kept in view. Among these are the liquefaction of natural gas (including its transportation over large distances) and the production of synthetic liquid fuels with the help of nuclear process heat. Beyond the time horizon of the scenarios considered here there are yet more options to be considered, such as nuclear fusion and centralized solar energy. Within the next fifty years, however, significant contributions are not to be expected from these latter sources.

5 ASSESSMENTS AND CONCLUSIONS

The analytical process described in the preceding sections emphasizes that an optimal energy strategy cannot be formulated for the European energy sector by isolating the European energy problem and designing technical or technoeconomic solutions. The scenarios developed in the earlier EC study *Crucial Choices for the Energy Transition* explore the range of normatively defined conservation and supply strategies. The *Crucial Choices* scenarios for the EC neglect quantitative feedbacks originating from other world regions also trying to deal with the worldwide energy problem. This could be corrected in an early phase of this study by taking account of the findings of the comprehensive study *Energy in a Finite World* by IIASA's Energy Systems Program. The effect, not surprisingly, is a substantial reduction in the economic growth projected for the EC. Figure 5.1 puts the various growth paths of the *Crucial Choices* study and of the present study

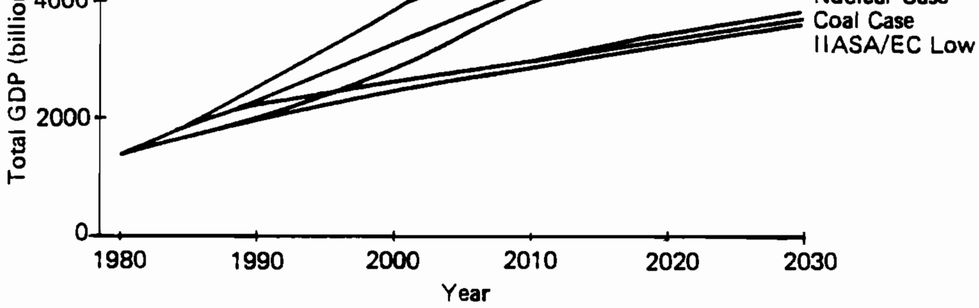

FIGURE 5.1 The GDP evolution in the EC for all scenarios.

into perspective. The two new scenarios IIASA/EC High and IIASA/EC Low embrace a range of GDP figures, falling short of the range explored in *Crucial Choices* by about 25% around the year 2030.

An independent investigation of the European energy problem has added to the technologically oriented strategies a macroeconomically consistent strategy for the EC energy system. The underlying idea was to postulate equilibrium conditions for the substitution of capital and labor for energy. Given the high productivity of capital and labor, all technically oriented energy strategies imply a degree of energy conservation and substitution away from oil that does not appear to be justified at the price level characteristic of the global supply opportunities.

Here a word of caution is appropriate. The adjusted global supply opportunities rest on the basic assumption of a cooperating world, a particular feature of the IIASA scenarios and thus also of the IIASA/EC High and IIASA/EC Low scenarios. In other words, the scenarios anticipate no new cartel-type supply organizations that might raise export prices for energy substantially above the cost price levels used for all non-oil energy trade in the scenario calculations.

Because of this internal macroeconomic inconsistency of all five *Crucial Choices* scenarios and the two IIASA/EC scenarios in Figure 5.1, a further macroeconomically consistent scenario was finally specified. It combines the GDP evolution of the IIASA/EC Low Scenario and the supply opportunities quantified with the IIASA/EC High Scenario. As an immediate consequence a technical option opens up in an otherwise extremely constrained supply situation of choosing between energy technologies that would suit other

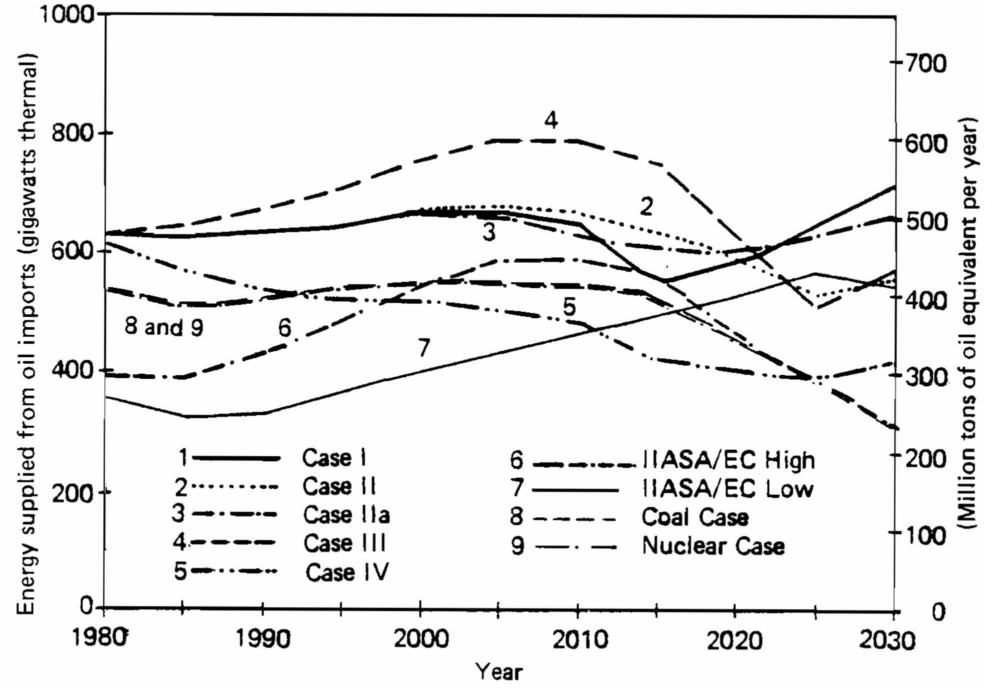

FIGURE 5.2 Summary of EC oil imports, all scenarios.

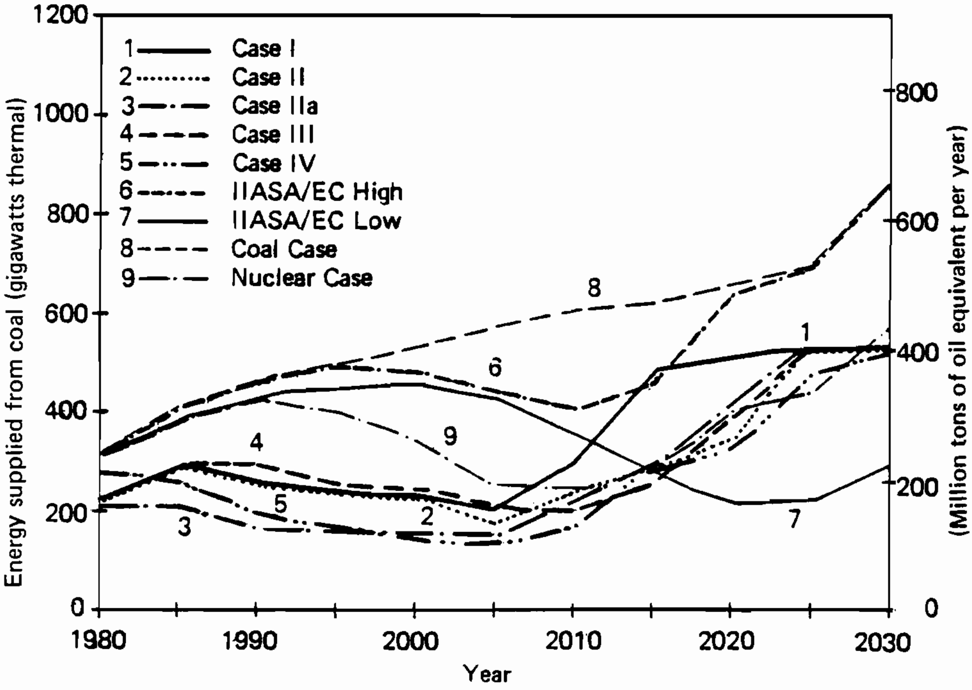

FIGURE 5.3 Summary of EC coal consumption, all scenarios.

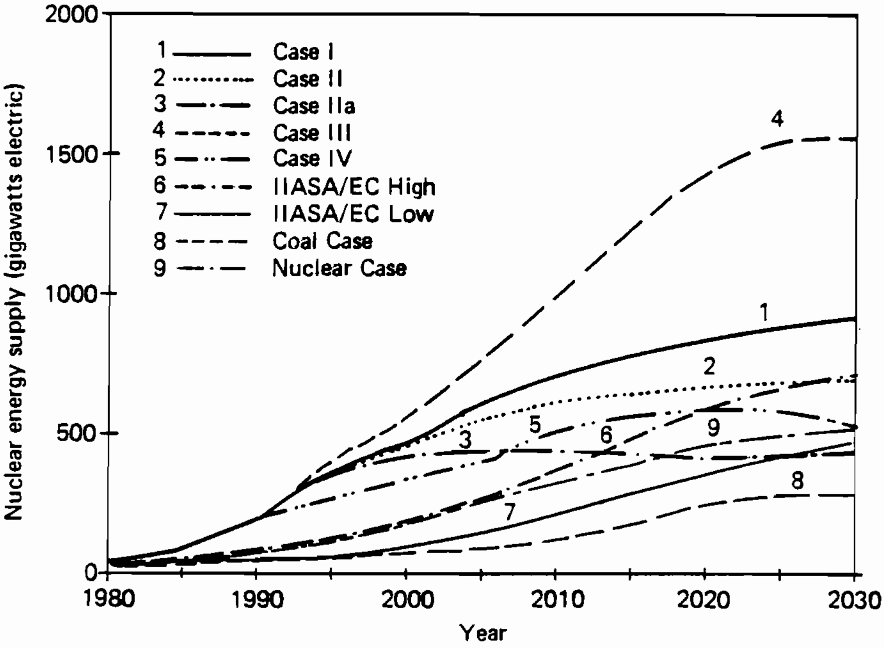

FIGURE 5.4 Summary of installed EC nuclear capacity, all scenarios.

objectives, e.g. social or environmental preferences. This flexibility is exemplified by the two scenarios labeled Coal Scenario and Nuclear Scenario.

The variations in oil imports, total coal consumption, and total installed nuclear capacity for all the scenarios in Figure 5.1 are given in Figures 5.2–5.4.

The nine scenarios can be seen as efforts to adapt the European energy system by technological change to an optimistically assessed global energy problem, conforming as closely as possible to a self-regulating macroeconomic optimization principle that ties the economic value of energy to the level of productivity of capital and labor: high capital and labor productivity require high energy prices to secure substantial energy conservation.

At this point a reassessment of the basic objectives behind each particular energy strategy or for that matter the assumptions behind each scenario becomes necessary. This reassessment must concentrate on the broader impacts of adopting a particular technological strategy. The question arises whether a reduction of an average unit of energy achieved in the scenarios of Figure 5.1 justifies a calculated loss of GDP on average five times larger than the economic value of the energy unit saved. A corollary question resulting from this study is whether price equilibria between capital, labor, and energy can and should be achieved in the future European economic system.

Clearly, the answers to such questions cannot be found by analyzing the potential role of alternative technological strategies in the energy system of the European Communities. The analysis illustrates, however, that whatever these answers are, they will have a decisive influence on the role particular energy technologies can play in Europe in the future.

ACKNOWLEDGMENTS

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APPENDIX
The MESSAGE Model

Introduction

The fundamental features of the MESSAGE model are summarized in Figure A.1. A number of primary energy sources and conversion technologies are considered. These include resources and technologies that could permit an essentially unlimited supply of energy – the fundamental point of the modeling being to explore possible transitions to energy system states based on more or less unlimited resources, such as thorium-232, uranium-238, and solar energy.

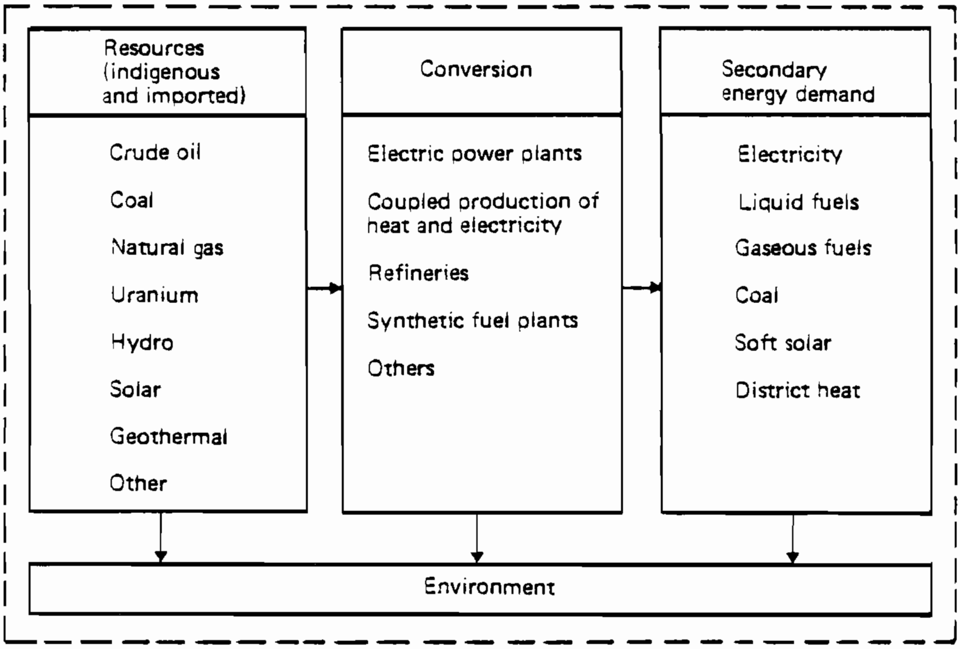

FIGURE A.1 Projection of useful and final energy demand in MEDEE-2.

Each primary energy source (except solar energy and hydroelectric power) is subdivided into an optional (chosen by the model user) number of classes in MESSAGE, taking account of the cost of extraction, the quality of resources, and the location of deposits. These primary sources are then converted directly (e.g. by crude oil refining) or indirectly (e.g. electrolytic hydrogen) into secondary energy. Secondary energy is exogenous to MESSAGE; data are provided via the MEDEE-2 model as time series data for electricity, soft solar energy, and solid, liquid, and gaseous fuels.

The variables of the model are expressed in period averages of annual quantities.

The objective function is the sum of discounted costs for fuels (primary energy), operation and maintenance, and capital costs for providing the energy demand over the time horizon for the study (1980–2030).

In the equations of the model – given approximately below – indices are sometimes omitted if this seems to facilitate understanding.

A comprehensive description of the MESSAGE model – its logic, mathematics, and scope – is available in Schrattenholzer (1981).

1 Inputs to the MESSAGE Model

This section describes the input data to the MESSAGE model for the IIASA/EC High and Low, EC Coal, and EC Nuclear scenarios (denoted as Case H, Case L, Case C, and Case N in what follows).

These data are compared with the EC data for one of the "bottom-up" runs described in *Crucial Choices*, namely the Acceptable Dependence Case (Case IIa). In some cases results (output data of MESSAGE) are reported so as to allow for better judgment of the input data.

All cost figures are in 1975 US dollars.

1.1 Data on Primary Energy Supply

1.1.1 Coal

Total availability: Cases H, L, C, and N

Category I ($33/kWyr): 55 TWyr*

Category II ($54/kWyr): 100 TWyr

Total availability: Case IIa

Category I ($35/kWyr): 65 TWyr

The actual usage in the scenarios is as shown in Table A.1.

TABLE A.1 Coal usage in the scenarios.

	Category I (TWyr)	Category II (TWyr)
Case H	19.8	0
Case L	16.7	0
Case C	19.8	0
Case N	17.7	0
Case IIa	12.0	0

The maximum annual extraction for all indigenous categories together is as shown in Table A.2. As mentioned in the main text, the extraction constraints have the same upper limits in all four IIASA scenarios.

The maximum annual coal imports are given in Table A.3.

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*kWyr, kilowatt-year; TWyr, terawatt-year (10^{12} watt-years).

TABLE A.2 Maximum annual coal extraction in the scenarios for all indigenous categories together.

Year	Cases H,C,N,L (GWyr)[a]	Case IIa (GWyr)
1980	270	290
1985	300	290
1990	320	290
1995	340	290
2000	360	290
2005	375	290
2010	390	290
2015	400	290
2020	400	290
2025	400	290
2030	400	290

[a] GWyr: gigawatt-year (10^9 watt-years).

TABLE A.3 Maximum annual coal imports in the scenarios.

Year	Cases H, C, and N (GWyr)	Case L (GWyr)	Case IIa (GWyr)
1980	40	40	85
1985	105	80	100
1990	140	110	115
1995	150	110	132
2000	170	100	150
2005	205	60	170
2010	215	0	191
2015	230	0	210
2020	260	0	226
2025	300	0	238
2030	470	0	250

Costs: Cases H, L, C, and N: $36/kWyr (constant); Case IIa: $45/kWyr (1980) rising to $50/kWyr (1990 and thereafter).

1.1.2 Oil

Total availability: Cases H, L, C, and N

Category I ($62/kWyr ≈ $12/barrel): 10.5 TWyr
Category II ($103/kWyr ≈ $20/barrel): 2.0 TWyr
Category III ($129/kWyr ≈ $25/barrel): 12.0 TWyr

Total availability: Case IIa

Category I ($43/kWyr ≈ $83/barrel): 4.6 TWyr
Category II ($75/kWyr ≈ $14.6/barrel): 6.8 TWyr

The actual oil usage in the scenarios is as given in Table A.4. As stated in the main text, the oil production figures for the IIASA High and Low scenarios were overly optimistic. They were adjusted in the Coal and Nuclear scenarios, resulting in a lower total consumption in these cases.

The maximum annual extraction for all indigenous categories together is as given in Table A.5.

TABLE A.4 Oil usage in the scenarios.

	Category I (TWyr)	Category II (TWyr)	Category III (TWyr)
Case H	10.5	2.0	0
Case L	10.5	0.25	0
Case C	9.8	0	0
Case N	9.8	0	0
Case IIa	4.6	4.0	0

TABLE A.5 Maximum annual oil extraction in the scenarios for all indigenous categories together.

Year	Cases C and N (GWyr)	Case H (GWyr)	Case L (GWyr)	Case IIa (GWyr)
1980	120	290	290	120
1985	160	310	310	160
1990	180	300	300	180
1995	190	270	265	190
2000	200	240	235	190
2005	210	210	200	190
2010	200	200	175	180
2015	180	180	145	165
2020	150	150	115	150
2025	180	180	77	115
2030	185	185	50	80

Costs: Cases H, C, N: $69/kWyr (1980); $106/kWyr (1990 and thereafter). Case L: $67/kWyr (1980), gradually increasing to $140/kWyr (2030).

As can be seen from this comparison, the extraction constraints in Cases C and N are a combination of the figure for Case H and those for Case IIa.

The maximum annual oil imports are given in Table A.6.

Since the limits on indigenous oil production were lowered in cases C and N (in comparison with case H), the constraints on oil imports were increased accordingly.

TABLE A.6 Maximum annual oil imports in the scenarios.

Year	Cases C and N (GWyr)	Case H (GWyr)	Case IIa (GWyr)	Case L (GWyr)
1980	660	490	No limit	445
1985	695	545		455
1990	720	600		480
1995	730	650		505
2000	740	700		530
2005	750	750		560
2010	650	650		570
2015	560	560		630
2020	450	450		635
2025	385	385		580
2030	300	300		540

In Case IIa there was no limit on annual imports. Instead, total imports (over the model time horizon) were restricted to 35 TWyr. For comparison, full utilization of the import possibilities in the IIASA scenarios would result in the following levels: for Cases C and N, 33.2 TWyr; for Case H, 30.4 TWyr; for Case L, 29.7 TWyr. The actual results for total oil imports are shown in Table A.7.

TABLE A.7 Total oil imports in the scenarios, 1980–2030 (TWyr).

	Total oil imports (TWyr)
Case H	25.5
Case L	24
Case C	27
Case N	27
Case IIa	35

TABLE A.8 Gas usage in the scenarios.

	Category I (TWyr)	Category II (TWyr)	Category III (TWyr)
Case H	12	2.6	0
Case L	8	0	0
Case C	12	2.6	0
Case N	12	2.6	0
Case IIa	6.1	2.0	0

1.1.3 Gas

Total availability: Cases H, L, C, and N

Category I ($62/kWyr): 12.0 TWyr
Category II ($103/kWyr): 3.0 TWyr
Category III ($129/kWyr): 9.0 TWyr

Total availability: Case IIa

Category I ($43/kWyr): 6.1 TWyr
Category II ($75/kWyr): 8.5 TWyr

The actual usages in the scenarios are as given in Table A.8.

The maximum annual extractions of gas for all indigenous categories together are given in Table A.9.

The maximum annual gas imports are shown in Table A.10.

1.1.4 Natural uranium

Total availability: Cases H, L, C, and N

Category I ($80/kgU ≙ $30/lb U_3O_8): 460 kt*
Category II ($130/kgU ≙ $50/lb U_3O_8): 1.2 Mt

Total availability: Case IIa

Category I ($80/kgU ≙ $30/lb U_3O_8): 250 kt
Category II ($130/kg U ≙ $50/lb U_3O_8): 350 kt

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*kgU, kilograms of uranium; kt, kilotons; Mt, megatons (10^6 tons).

TABLE A.9 Maximum annual gas extraction in the scenarios for all indigenous categories together.

Year	Cases H, C, and N (GWyr)	Case L (GWyr)	Case IIa (GWyr)
1980	250	220	200
1985	255	200	192
1990	260	190	181
1995	265	175	169
2000	270	165	160
2005	270	155	150
2010	270	140	140
2015	270	120	130
2020	270	100	120
2025	270	75	100
2030	270	50	80

TABLE A.10 Maximum annual gas imports in the scenarios.

Year	Cases H, L, C, and N (GWyr)	Case IIa (GWyr)
1980	No limits	200
1985		215
1990		240
1995		280
2000		325
2005		370
2010		410
2015		440
2020		440
2025		440
2030		440

Costs: Cases H, L, C, and N: $66/kWyr (1980), gradually increasing to $119/kWyr (2010) and constant thereafter. Case IIa: $47/kWyr (1980), gradually increasing to $100/kWyr (2030).

TABLE A.11 Uranium usage in the scenarios.

	Category I (kilotons)	Category II (kilotons)
Case H	460	810
Case L	460	163
Case C	460	615
Case N Low	460	566
Case IIa	250	90

Actual usage in the scenarios is as given in Table A.11.

The maximum annual extraction for all indigenous categories together is as given in Table A.12.

No limits are imposed in Case IIa on annual imports of natural uranium. However, total imports in this case are limited to 2 Mt, at costs of $83/kgU (1980), gradually increasing to $174/kgU (2030), 1.13 Mt of which are used.

TABLE A.12 Maximum annual uranium extraction in the scenarios for all indigenous categories together.

Year	Cases H, L, C, and N (kilotons)	Case IIa (kilotons)
1980	No limits	4.8
1985		6.5
1990		7.0
1995		8.5
2000		10.0
2005		11.0
2010		10.0
2015		8.0
2020		6.0
2025		4.5
2030		3.5

TABLE A.13 Hydroelectric power capacity in the scenarios.

	Cases H, L, C, and N	Case IIa
Capacity (1975) (gigawatts)	43	29
Asymptote (gigawatts)	42.5	45
Capacity factor	0.5	0.5

No imports are taken into account in the other scenarios. This is more a technical question than a reflection of reality. The main text describes how the assumptions in these scenarios with respect to natural uranium should be interpreted.

1.1.5 Thorium

The H, L, C, and N scenarios do not consider high temperature reactors; the only case in which thorium is consumed is Case IIa. Even in this case thorium does not play a significant role.

1.1.6 Hydroelectric power

The actual electrical energy generated by hydroelectric power in 1975 was 14.5 GWyr; the installed capacity was 43 GW (see Table A.13). This means that Cases H, L, N, and C assume the right capacity whereas Case IIa assumes the right amount of energy produced from hydro power. Although they do not influence the solutions significantly, these discrepancies represent mistakes that were overlooked.

1.1.7 Nuclear power

Only Cases H, L, C, and N have constraints on total nuclear capacity. These are as shown in Table A.14.

These constraints reflect a limitation on the total annual addition to nuclear capacity. This means that the maximum capacity at a given time can only be attained if the maximum capacity additions are made in all time periods up to this point.

TABLE A.14 Constraints on the growth of total nuclear capacity in the scenarios.

Year	Cases H, C, and N (GW)	Case L(GW)
1980	29	23
1985	48	31
1990	77	46
1995	120	68
2000	182	100
2005	262	141
2010	372	212
2015	500	302
2020	652	424
2025	726	510
2030	803	530

No limit on total nuclear capacity was imposed on the model for Case IIa. In this case the build-up of nuclear capacity was constrained only by the market penetration constraints and by the date of introduction of new nuclear technologies. These constraints have the following form:

$$y_t^t \leqslant \gamma y^{t-1} + g$$

where y^t is the annual increment of capacity in time period t, γ is the growth parameter, and g is the parameter that permits the starting-up of a technology. If capacity were to be increased to the limits of the constraints, after three to four time periods the total increase would generally be more than could be utilized. The constraints therefore limit the rate of build-up rather than the total capacity. For this reason, they were also employed in cases H, L, C, and N, in addition to the limits on total capacity.

TABLE A.15 Input data for nuclear power in the scenarios.

	γ	g	Start-up date
Cases H,L,C,N			
Light water reactor	1.5	1	No constraint
Fast breeder reactor	2	1	2000
High temperature reactor	n.a.	n.a.	n.a.
Case IIa			
Light water reactor	2	1	No constraint
Fast breeder reactor	2	1	2000
High temperature reactor	2	6	2005

n.a.: not applicable.

The input data are as shown in Table A.15.

As an indication of the extent to which the constraints were effected, the actual nuclear capacities in all cases for 2030 are given in Table A.16.

TABLE A.16 Nuclear capacity in the year 2030 in the scenarios.

	Light water reactor (GWe)[a]	Fast breeder reactor (GWe)	High temperature reactor (GWe)	Total (GWe)
Case H	222	497	–	719
Case C	283	0	–	283
Case N	129	404	–	533
Case IIa	30	345	78	453
Case L	89	357	–	446

[a] GWe: gigawatts electric (10^9 watts).

TABLE A.17 Data on electricity generation.

	Capital costs ($/kW)[a]	Running costs ($/kWyr)[b]	Maximum availability (fraction)	Product cost ($/kWyr)
Light water reactor				
Cases H,L,N	700	50	0.7	136
Case C	1400	50	0.7	207
Case IIa	525	42	0.7	111
Fast breeder reactor				
Cases H,L,N	920	50	0.7	143
Case C	1850	50	0.7	237
Case IIa	940	41	0.7	136
Coal				
Cases H,L,C,N	550	23	0.7	171
Case IIa	460	19	0.7	163
Advanced coal[c]				
Cases H,L,C,N	480	36	0.7	167
Case IIa	400	30	0.7	158
Hydro power				
Cases H,L,C,N	620	8.5	0.5	85
Case IIa	520	7.0	0.5	81
STEC[d]				
Cases H,L,C,N	1900	60	0.57	297
Case IIa	1900	60	0.57	297
Oil-fired power plant				
Cases H,L,C,N	350	19	0.7	247
Case IIa	310	16	0.7	191
Gas-fired power plant				
Cases H,L,C,N	325	16	0.7	216
Case IIa	300	13	0.7	160
Gas turbines				
Cases H,L,C,N	170	17	0.7	241
Case IIa	220	13	0.7	180

[a] US(1975) dollars per kilowatt.

[b] US(1975) dollars per kilowatt-year.

[c] Advanced coal means a cheaper (in terms of capital costs), more efficient, and cleaner technology, e.g. fluidized bed combustion.

[d] STEC includes some storage (plant factor up to 57%) and extra transmission costs (expressed as high running costs).

1.2 Data on Technologies

The costs of technologies, their maximum availability (as an average percentage of time), and a product price that is the result of a simple static cost calculation made by using an annuity factor to arrive at levelized capital costs, are described in the following. Other simplifying assumptions had to be made to arrive at a single figure for product costs. These are firstly that capacity is fully utilized, and, secondly, that the fuel costs are given by the figure for cost category I of the relevant fuel input. The resulting product costs can provide a yardstick for the preference ranking done by the linear programming model, which depends also on a dynamic relation within the model. In addition, it should be kept in mind that the tight constraints on resource availability usually mean that the area within which the cost data determine the optimal solution is rather small. The cost figures should therefore be regarded more as a technical means of expressing the preference ranking of the technologies than as actual costs.

1.2.1 Electricity generation

See Table A.17.

1.2.2 Other technologies

See Table A.18.

TABLE A.18 Data on other technologies.

	Capital costs (\$/kW)[a]	Running costs (\$/kWyr)[b]	Maximum availability (fraction)	Product cost (\$/kWyr)
High temperature reactor gasification				
Cases H,L,C,N	–	–	–	–
Case IIa	550	19.4	0.85	73
Autothermal coal gasification				
Cases H,L,C,N	480	40	0.85	135
Case IIa	400	30	0 85	122
Autothermal coal liquefaction				
Cases H,L,C,N	480	40	0.85	135
Case IIa	400	30	0.85	122
Crude oil refinery				
Cases H,L,C,N	50	3.7	0.85	75
Case IIa	43	3.1	0.85	53

Note: The high temperature reactor of the design used for Case IIa produces electricity as a side product. The cost of its main output (gas) was reduced by an amount representing the value of the electricity.

[a] US(1975) dollars per kilowatt thermal energy content of product output.

[b] US(1975) dollars per kilowatt-year thermal energy content of product output.

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