# TWO GLOBAL SCENARIOS: THE EVOLUTION OF ENERGY USE AND THE ECONOMY TO 2030

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# FOREWORD

*Energy in a Finite World: A Global Systems Analysis* (Ballinger, Cambridge, Massachusetts, 1981, 880 pages) documents the seven-year study of the future balance of energy supply and demand made by the IIASA Energy Systems Program. Part IV of this book, "Balancing Supply and Demand: The Quantitative Analysis," presents results based on two scenarios of global and regional development. Based on the data available when the work was done, these scenarios specify population growth, aggregate economic development in five sectors, and detailed energy use and supply for seven global regions. The scenarios specify energy requirements for households, transportation, and economic activity, and estimate energy supply regionally and globally. These scenario specifications and their derivations are supported by the IIASA set of energy models (see Energy Program Group 1981).

This report describes and analyzes these scenario projections within the economic framework, including aggregate economic models, that was used in deriving the projections.

To understand the context of this report and to appreciate the full range of its findings, one must read it in conjunction with the book cited above.

Other related energy publications are listed at the end of this report.

WOLF HÄFELE
*Leader*
Energy Systems Program

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## SUMMARY

Energy in a Finite World: A Global Systems Analysis *documents the seven-year study of the future balance of energy supply and demand made by the IIASA Energy Systems Program. Part IV of this book, "Balancing Supply and Demand: The Quantitative Analysis," presents results based on two scenarios of global and regional development; these scenarios specify population growth, aggregate economic development in five sectors, and detailed energy use and supply for seven global regions. This report outlines how these scenarios were derived and interprets their quantitative projections in terms of energy–price, energy–income, and substitution elasticities and technological development. The data used are those also used in the book.*

*This report defines the scenarios in terms of population, GDP, and primary and final energy-use projections in sufficient detail for the economic interpretation analysis. For all seven regions, it examines the energy linkage in the aggregate in terms of energy use per unit of GDP and the energy–GDP elasticity, after which it defines an economic framework and simple aggregate models for interpreting the scenario projections. One model allows for separating the effects of energy prices and energy growth on energy requirements; another, based on a production-function formulation, allows one to examine technological development and the substitution of nonenergy for energy inputs primarily in the industrial sector. Finally, the report defines appropriate measures of energy price increases over the projection period and uses them, along with the economic models, to analyze the scenarios in economic terms.*

## 1 INTRODUCTION

A scenario is a logically consistent statement or characterization of a possible future state of the world. Often a scenario statement also specifies a sequence of events that could transform a reference state into the postulated future state. This postulated state may represent the consensus of many experts or be outrageously absurd, provided that it is internally consistent and follows from the assumptions made. A scenario in this sense, therefore, is not a prediction, but simply one future state that might be realized.

Scenario definition is necessarily subjective. Many assumptions must be made which cannot be proven or tested. Depending on one's purpose, certain assumptions are more appropriate and more useful, than others. We use our scenario projections as a tool to explore the interrelationships among many variables. We have developed two quantitative scenarios in detail which we label High and Low. Neither represents our expected or most likely future. But the range of the High and Low is sufficient to span many possible future states which are useful to explore.

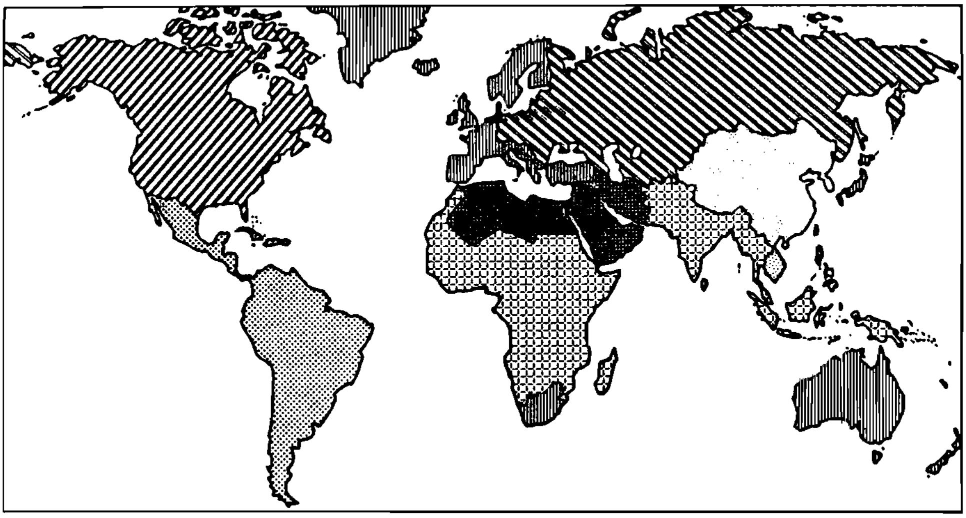
No one would claim that the product of the IIASA Energy Systems Program was, in whole or in part, two scenarios. Scenarios *were* developed, *were* used as a learning tool, and formed a framework within which to describe results in an internally consistent and quantitative manner. The drive for consistency demanded quantification, usually to a precision well beyond what would be justified based on data availability and known relationships. That is the nature of the analytic tool. One must not forget, however, the purpose of the quantification and the scenario projections; the message must be interpreted.

Most of the work documented in this report involved the interpretation, in economic terms, of scenario projections that were derived in noneconomic terms. That is to say, our scenario projections were derived based on assumptions about population, production, resources, costs, development, technology, and life-styles with the assistance of a set of detailed models. These projections were then interpreted in economic terms using energy prices, income and price elasticities, technological development and substitution. The purpose of these interpretations was twofold. Firstly, to use the interpretation as part of the assessment of the scenario during the iterative development process with respect to consistency, reasonableness, and continuity. Secondly, to provide, as in this report and other publications, a similar interpretation of the resulting scenarios to facilitate understanding and comparisons with other work. This report also serves another purpose in providing a more detailed scenario data base, both historical and projected, than Energy Program Group 1981.

## 1.1 Two Scenarios

Our two scenarios were developed to enable the analysis of the global energy problem to be specific, regional, and quantitative. In a highly aggregated way, these scenarios provide a high and a low energy use picture for each of seven regions of the globe. These regions are illustrated in Figure 1 and are defined in Appendix B.

To begin the scenario development process, assumptions were made with respect to population growth and urbanization. Population projections for the seven regions exhibit continually decreasing growth rates reaching a stable population of some nine billion people a few decades after our projection period. During the projection period (1975–2030), global population doubles from four billion to eight billion – an abrupt change in historical perspective. Also the population share in developing regions increases from 71



| | | |
|---|---|---|
| Region I | (NA) North America |
| Region II | (SU/EE) Soviet Union and Eastern Europe |
| Region III | (WE/JANZ) Western Europe, Japan, Australia, New Zealand, S. Africa, and Israel |
| Region IV | (LA) Latin America |
| Region V | (Af/SEA) Africa (except Northern Africa and S. Africa), South and Southeast Asia |
| Region VI | (ME/NAf) Middle East and Northern Africa |
| Region VII | (C/CPA) China and Centrally Planned Asian Economies |

FIGURE 1 The IIASA world regions.

percent to 80 percent; the population ages such that two-thirds as many people are in the labor-force age bracket (15–65 years) per person over age 65; and urbanization increases dramatically from 30 percent to 60 percent in the developing regions and from less than 70 percent to 90 percent in developed regions. The same population projection was used in both scenarios and it was not changed during the iterative process.

A second major starting point in the scenario development process was projection of gross domestic product (GDP) for each region. Two projections were made, a high and a low. GDP was included within the iterative process so that initial projections were not necessarily our final projections. These scenarios exhibit ever-decreasing growth rates through the projection period, on both a per-capita and absolute basis. Also the developing region growth rates were consistently higher than those in Regions I and III, again, even on a per-capita basis. GDP projections were disaggregated into five major sectors including manufacturing which was further disaggregated for purposes of analyzing energy requirements. The sectoral shifts during the projection period included an increasing share of services in developed regions and an increasing share of the industry sector (replacing agriculture) in the developing regions.

Energy requirements were projected in detail for household and commercial use, for transportation, for economic sectors, and for feedstocks. These requirements were defined at the useful energy level wherever possible and were transformed into requirements for final energy. Total final energy projections increase 4-fold in the High scenario (from 5.8 to 22.8 TWyr/yr) and 2.5-fold in the Low scenario (from 5.8 to 14.6 TWyr/yr). (See Appendix C for energy units and conversion factors.)

Primary energy requirements were computed with a cost minimizing model designed to meet energy demand while accounting for constraints on total resources, build-up rates, maximum production levels and availability of imports. Global primary energy projections increase 4.3 times in the High scenario (from 8.2 to 35.7 TWyr/yr) and 2.7 times in the Low scenario (from 8.2 to 22.4 TWyr/yr). On a per-capita basis, global average primary energy increases from 2.1 to 4.5 kWyr/yr (High) and 2.8 kWyr/yr (Low).

### *1.1.1 IIASA Energy Models*

These scenario projections were developed in detail for each region with the help of the IIASA set of energy models (Basile 1980). Population and economic projections were used as basic driving variables for determining energy consumption requirements in final and useful energy terms by means of the MEDEE model as depicted in Figure 2. This model, which accounts for all forms of energy end-uses, is primarily involved with physical relationships. Projections used in the model are made based on a general hypothesis of higher energy prices and conservation rather than on energy prices and price elasticities directly.

This detailed specification of energy demand is translated for use as the driving input for an optimizing supply model called MESSAGE (Schrattenholzer 1981). This model devises a minimum cost strategy for satisfying the energy demands taking account of resource availabilities and costs, technology costs, new technology build-up constraints, and availabilities of imported energy resources. The results are projections of primary energy requirements by region and shadow costs for each constraint. Several iterations are required to obtain a satisfactory solution in terms of both interregional balances of traded energy and intraregional consistency between energy demand by fuel type and energy supply. As shown in Figure 2, the results of the supply strategy are then analyzed in further detail to determine capital requirements and economic impacts.

Also shown in this figure is an economic interpretation block which takes data from the basic input assumptions, the MEDEE model, and the MESSAGE model, in order to determine energy prices and various elasticities. It is this block which is the focus of this report.

The purpose of performing this economic interpretation is two-fold. One purpose is to derive a better understanding of the implications of the scenario projections and, if necessary, to provide guidance for changing these projections. A second purpose is to interpret the scenario projections, that were made primarily without using energy prices and elasticities, in economic terms in order to facilitate comparisons with other studies and to allow others to interpret our projections in different ways.

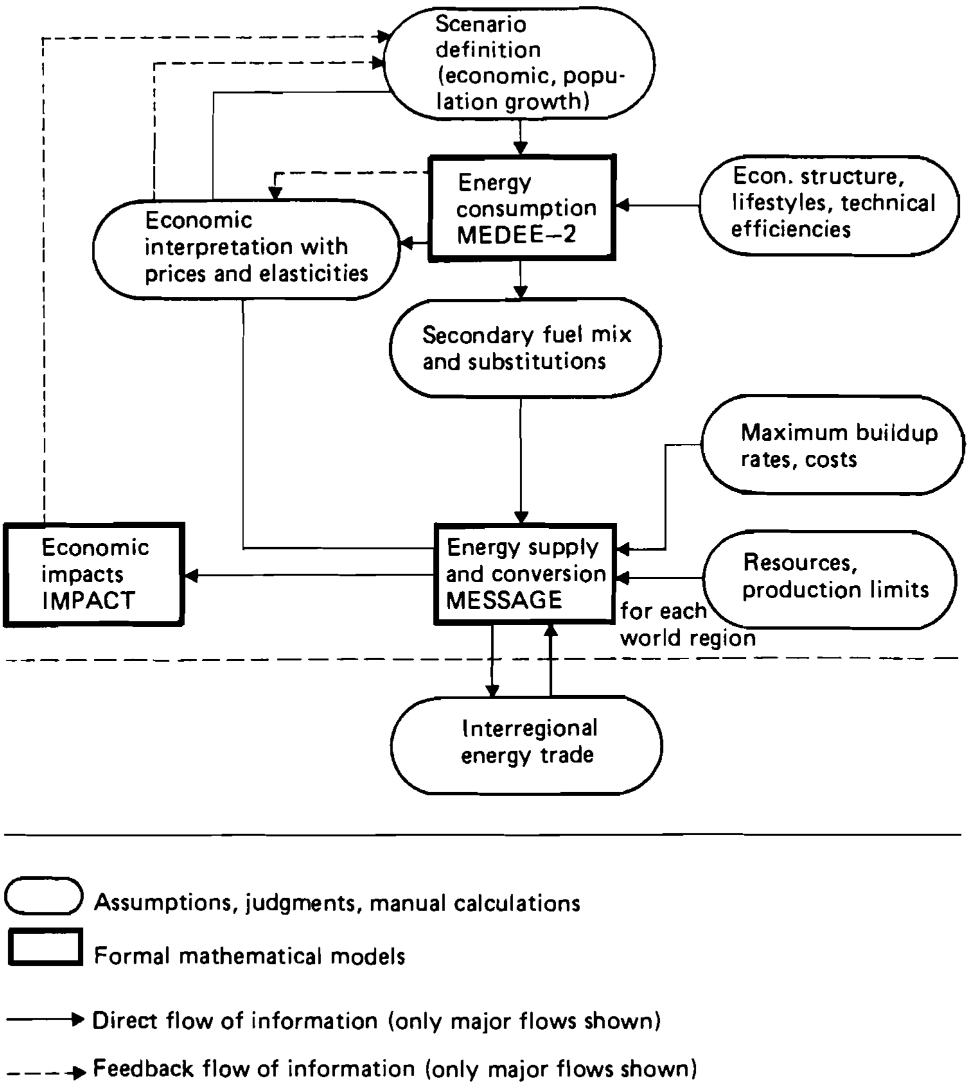



FIGURE 2 The IIASA set of models for energy program scenario development.

### *1.1.2 Aggregate Energy–Economy Linkage*

A convenient way of specifying the linkage between energy requirements and economic growth is by means of the energy–GDP elasticity. An elasticity of unity implies that energy growth and economic growth go hand in hand: a 10 percent increase in GDP requires a 10 percent increase in energy. Lower values of elasticity imply that energy requirements increase proportionally less than GDP increases. For primary energy, historical values of this elasticity are close to unity for Region I and Region III but the scenario projections exhibit much lower values of about 0.7. This indicates that energy conservation is included in the projections. In the short term (to 2000) in Region I, much smaller values of about 0.4 indicate the potential for strong conservation, especially in the transportation sector. The developing regions, on the other hand, exhibit elasticities much greater than unity. These values do not imply increasing inefficiency, but are caused by a changing economic structure toward increasing energy use in agriculture and toward energy-intensive industry during the development process. These elasticities do drop from historical values of 1.2 to 1.5 down to near unity in the course of the projection period.

### *1.1.3 Energy Prices*

The aggregate energy–GDP elasticity does not separate the effect of energy prices on energy use. It is clear that energy prices are increasing and prices do make a difference. Another simple model has been used to separate the effects of energy consumption increases due to GDP increases and energy conservation due to energy price increases. In this model, two elasticities are defined, one analogous to the aggregate energy–GDP elasticity mentioned above and another to measure the response to price increases. Energy price increases appropriate for use in this model are for final (delivered) energy, in real (constant) terms (excluding general inflation). It is argued that price increases relative to 1972 price levels are most appropriate even though the study base year is 1975. The reason is that the ultimate effects of real price increases between 1972 and 1975 (about 40 percent) had not taken place by 1975. As a guide for defining prices, projected increases in energy production and distribution costs are examined. Long-term price increases for final energy (averaged over all forms of energy including electricity) are then set at a factor of three for all regions except Region III. This region had relatively high prices in 1972 and so the long-term increase there was set at 2.4.

Using these projected price increases and the scenario projections for GDP and total final energy, combinations of energy–income elasticities (same as elasticities mentioned above *if* prices are constant) and energy–price elasticities were calculated consistent with the scenarios. These price elasticities ranged from − 0.2 to − 0.85 in the developed regions and from 0.0 to − 0.5 in the developing regions.

### *1.1.4 Payments for Energy*

The combination of increasing energy use and increasing energy prices results in greatly increased payments for energy over the projection period. In the developed regions, energy conservation (energy–GDP elasticities less than unity) softens the impact of increasing energy prices such that payments for energy increase, relative to GDP, from 20 to 35 percent in High scenario and from 40 to 70 percent in Low scenario. The greatest impact, however, is in the developing regions where increasing energy intensiveness, coupled with price increases, result in 3- and 4-fold increases in payments as a share of the GDP. These increases are staggering and signal ever-increasing strains on world economic order.

### *1.1.5 Sectoral Energy Use*

Energy requirements must be modeled on a detailed basis. The aggregate analyses summarized above are useful for understanding the overall scenario projections. More insight is gained by examining the various uses of energy and how these uses are related to economic activity and energy prices.

We distinguish between energy used as a factor of production in the economy and energy purchased by consumers. The former is an intermediate input to a production process that requires other inputs as well, most importantly capital and labor. Energy purchased by consumers for household use or for passenger transport, we call final demand energy. Final demand energy is used directly by the consumer while intermediate input energy is used indirectly.

A comparison of final demand and intermediate input energy use in the scenario projections indicates that the energy–income and energy–price elasticities are different for the two categories of energy use. For the developed regions, energy conservation is more pronounced for final demand energy than intermediate input energy (very strong in the High and less strong in the Low scenario). For the developing regions, the opposite is indicated, but less pronounced. The linkage of final demand energy to population and the great potential for conservation in developed regions would explain these results.

### *1.1.6 Substitution and Technological Development*

A framework for analyzing the substitution between energy as a factor of production, and capital and labor as other factors of production is defined in the report. This framework is based on a constant elasticity of substitution production function incorporating an exponential (with time) technological development factor which allows for more production from the same inputs as time progresses. Making use of the economic concept of setting prices equal to marginal productivity, energy and other factor prices are defined. It is shown how, with the assumed technological development factor, factor prices must increase over time in real terms to keep up with their marginal productivity. Energy price increases greater than those accounted for by technological development cause a substitution of other factors of production (capital and labor) for energy. The reduction in energy growth due to technological development and substitution is most evident in one summary equation that expresses the energy–GDP elasticity $\epsilon$ in terms of the exponential growth rates of GDP $g$, of technological development $\delta$, and of energy prices $\pi$, and the elasticity of substitution $\sigma$ (which is shown in the report to be closely related to an energy–price elasticity):

$$\epsilon = 1 - \delta/g - \sigma(\pi - \delta)/g$$

As indicated in this equation, energy growth relative to GDP growth is less than unity due to technological development (the strength of the effect due to the ratio of technological development "growth" $\delta$ and GDP growth $g$) and due to substitution provided energy prices $\pi$ increase faster than what is accounted for by technological development $\delta$. In the examples calculated in the report consistent with the scenario projections, the relative contribution of these two terms in reducing $\epsilon$ is shown to be somewhat less than one half due to technological development.

In the application of the substitution model to the industry sector of six regions, technological development ranges from 0.2 to 0.6 percent per year. Region II indicates the largest values, Regions I and III next with the developing regions having the lowest values. Similarly, the elasticities of substitution (closely related numerically to energy price elasticities) range from 0.2 to 0.6 with the same regional variation. The model also indicates that the increase in other factors of production due to energy price increases and substitution would be relatively small: between 0.7 and 1.9 percent for all regions except Region II which would be about 2.5 percent.

These relatively small increases in use of nonenergy factors of production due to substitution result from price increases of only energy. Other resource-based inputs are expected to exhibit real price increases as well which will cause their own substitution effect.

## 2 TWO SCENARIOS: DEFINITION AND ENERGY–ECONOMY LINKAGE IN THE AGGREGATE

This section is divided into two parts. The first part summarizes the two IIASA Energy Program scenarios. The scenarios are defined by specifying the population projections for seven world regions for the period 1975–2030, by specifying two economic projections (a High economic growth and a Low economic growth), and by specifying the energy consumption accompanying these projections (a High and a Low). The energy projections, which are based on the population and economic projections as major inputs, are described in Energy Program Group (1981) from the demand, as well as the supply, points of view.

The second part examines the demand linkage between the economy and energy consumption for the aggregate regional economies. This aggregate analysis is performed in terms of energy–GDP ratios, energy–GDP elasticities, and income and price elasticities for all seven regions.

### 2.1 Scenario Definition

#### *2.1.1 Population Projections*

The population of the world is already in excess of four billion ($10^9$) with over 70 percent in developing regions. At current growth rates, the population would double in 35 years. No present day demographer, however, would project world population for the next 35 or 50 years with today's growth rate.

Examination of the world population over the past two centuries shows that growth rates have varied considerably. As shown in Table 1, the growth rate for the world as a whole has increased from 0.4 percent per year in 1750 to 1.9 percent per year in 1975. These world average growth rates, however, do not indicate the large changes that have taken place separately in the more developed and less developed countries. The more developed countries have experienced a rapid increase in growth rate up to the middle of the nineteenth century and a gradual leveling off. The less developed countries have had very low and decreasing growth rates in the previous century but have recently shown very high growth rates.

For projection purposes, the factors that influence birth rates and death rates must be well understood. By making assumptions about these factors, conditional projections can then be made. Under certain conditions, it is possible and desirable to link these factors to other scenario parameters and projections (e.g., economic development, energy use) and, therefore, to make population projections scenario dependent. This was not done.

TABLE 1 World population for two centuries.

| | 1750 | | 1800 | | 1850 | | 1900 | | 1950 | | 1975 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Population* | | | | | | | | | | | |
| ($\times 10^6$) | 791 | | 978 | | 1,262 | | 1,650 | | 2,492 | | 3,946 |
| *Distribution* | | | | | | | | | | | |
| (percent) | | | | | | | | | | | |
| More developed countries | 26 | | 26 | | 28 | | 35 | | 34 | | 27 |
| Less developed countries | 74 | | 74 | | 72 | | 65 | | 66 | | 73 |
| *Growth rates* | | | | | | | | | | | |
| (percent/year) | | | | | | | | | | | |
| More developed countries | | 0.4 | | 0.7 | | 1.0 | | 0.8 | | 0.9 | |
| Less developed countries | | 0.4 | | 0.5 | | 0.3 | | 0.8 | | 2.2 | |
| World | | 0.4 | | 0.5 | | 0.5 | | 0.8 | | 1.9 | |

We preferred to work with a single, fixed projection of population that fell within the range of our own population projections as well as numerous other recent population projections. This is not to deny the existence or importance of economic and environmental factors on population. This approach was taken partly in order to reduce the complexity of analysis but mainly to focus our attention on the energy and energy–economic implications of the global energy system.

The population projections we have used are based on the assumptions of achieving a bare replacement level of fertility in developing regions by 2015 (Keyfitz 1977). These population projections for the seven geographical world regions are presented in Table 2 and are illustrated in Figure 3. The current population growth rate and the assumed future decline in growth rate are put into perspective with the historical data from Table 1.

A more detailed look at the projected growth of the world population shows a gradual decrease from its current peak of 2 percent per year to less than 1 percent per year by 2030. The growth rates of the less developed regions (IV, V, and VI), however, are more than three times the growth rates of the more developed regions (I, II, and III). As shown in Table 3, the projected growth rates for Region VII, are in between those of the Regions I, II, and III and Regions IV, V, and VI.

There is a striking change in the age structure as this projected stable population is approached. As a result of a lower birth rate and an increasing life expectancy, especially in developing regions, the fraction of population over age 65 increases substantially. Since this has an impact on average economic productivity and growth potential, it is an important factor in setting scenario values. To see this effect look at the ratio of population between the ages of 15 and 64 to the population age 65 and over. In simplistic terms, this ratio indicates the number of people who must produce not only for themselves and their children, but also for one additional adult who has retired from economic production. In 1975 in Region I, there were 6.4 persons between 15 and 64 years for each person 65 and over. By 2030, this ratio will be 4. Regions II and III exhibit a similar pattern by dropping from 6.7 and 5.7 respectively to about 4 by 2030. Regions IV, V, and VI will change more dramatically by dropping from a range of 15–18 down to 8–9 by 2030 while Region VII drops from 11 to 5.5.

TABLE 2 Scenario definition part 1: Population projection by region[a].

| | Population ($\times 10^6$) | | | | |
|---|---|---|---|---|---|
| | Base year | | Projection[c] | | |
| | (actual[b]) 1975 | 1985 | 2000 | 2015 | 2030 |
| Region I<br>North America | 237 | 257 | 284 | 302 | 315 |
| Region II<br>The Soviet Union and E.Europe | 363 | 393 | 436 | 467 | 480 |
| Region III<br>W. Europe, Japan, Australia, New Zealand, S. Africa, and Israel | 560 | 611 | 680 | 727 | 767 |
| Region IV<br>Latin America | 319 | 424 | 575 | 693 | 797 |
| Region V<br>Africa (except Northern Africa and S. Africa), South and Southeast Asia | 1,422 | 1,860 | 2,528 | 3,080 | 3,550 |
| Region VI<br>Middle East and Northern Africa | 133 | 176 | 247 | 302 | 353 |
| Region VII<br>China and Centrally Planned Asian Economies | 912 | 1,097 | 1,330 | 1,550 | 1,714 |
| World | 3,946 | 4,818 | 6,080 | 7,121 | 7,976 |

[a] See Appendix B for a complete listing of countries in each region.
[b] Mid-year estimates from UN 1978.
[c] Same population projection for both High and Low scenarios.

### *2.1.2 Economic Projections*

Global economic production exceeded $6 \times 10^{12}$ US dollars in 1975 (base year for projections). Many caveats and explanatory notes must be added to this statement before it can be properly interpreted. It is, however, the measure of the "size" of the global economic system that we have chosen to use.

The explanatory notes include the following: we use 1975 US dollars, 1975 official exchange rates and prices (except for centrally planned economies*), and we measure GDP by country, then aggregate to our seven regions and finally the globe. The caveats

*For the centrally planned economies we used the estimates of GDP given by World Bank (1977). These estimates are based on a comparison of physical indicators of economic product among centrally planned and market economies for 1965 (this comparison was done by the UN Economic Commission for Europe). Then data for real growth for both centrally planned and market economies were used to estimate the GDP of the centrally planned economies for 1975.

include the obvious ones involved whenever GDP estimates of different countries are compared or aggregated into regions. Economic structures are very different from country to country (especially from developing to developed economies) and so GDP estimates are not really comparable; and also official monetary exchange rates do not necessarily reflect "real" equivalences.

Given these caveats, the estimates of GDP for 1975 for our seven regions are given in Table 4. The historical growth rates of GDP are also given for the period 1950–1975 for GDP as measured in constant prices of 1975. The same data are given in per-capita terms in Table 5.

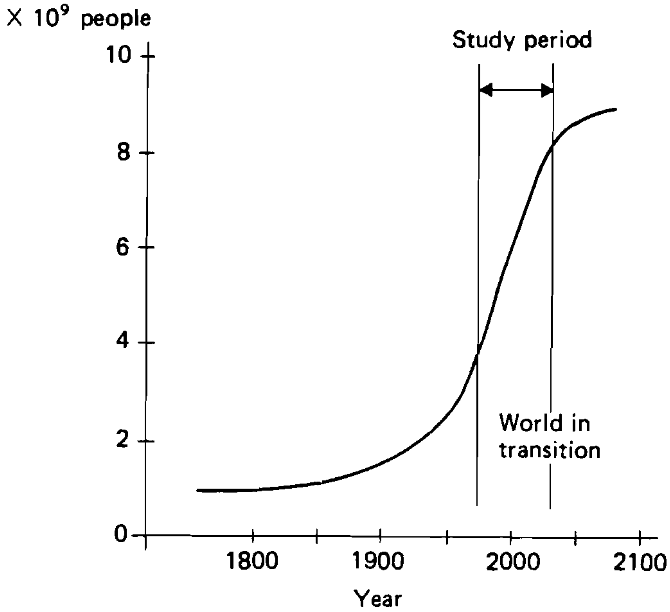



FIGURE 3 World population: historical and projected.

TABLE 3 Population growth rates.

| | Average annual growth rate (percent/year) 1950–1975 | 1975–1985 | 1985–2000 | 2000–2015 | 2015–2030 |
|---|---|---|---|---|---|
| Developed regions (I + II + III) | 1.2 | 0.8 | 0.7 | 0.4 | 0.3 |
| Developing regions (IV + V + VI) | 2.4 | 2.8 | 2.1 | 1.3 | 1.0 |
| Region VII (C/CPA) | 1.7 | 1.9 | 1.3 | 1.0 | 0.7 |
| World | 1.9 | 2.0 | 1.6 | 1.1 | 0.8 |

TABLE 4 Estimates of GDP for 1975 and historical growth rates[a].

| Region | Growth rate (percent/year) 1950–1960 | 1960–1975 | 1950–1975 | GDP $\$10^9$ 1975 |
|---|---|---|---|---|
| I (NA) | 3.3 | 3.4 | 3.4 | 1,670 |
| II (SU/EE) | 10.4 | 6.5 | 8.0 | 930 |
| III (WE/JANZ) | 5.0 | 5.2 | 5.1 | 2,385 |
| IV (LA) | 5.0 | 6.1 | 5.7 | 340 |
| V (Af/SEA) | 3.9 | 5.5 | 4.9 | 340 |
| VI (ME/NAf) | 7.0 | 9.8 | 8.6 | 190 |
| VII (C/CPA) | 8.0 | 6.1 | 6.9 | 320 |
| World | 5.0 | 5.0 | 5.0 | 6,175 |

[a]GDP in 1975 dollars and prices using official exchange rates for market economies. See Table A.2 in Appendix A.

TABLE 5 Estimates of per capita GDP for 1975 and historical per capita growth rates.

| Region | Per capita growth rate (percent/year) 1950–1960 | 1960–1975 | 1950–1975 | Per capita GDP \$ 1975 |
|---|---|---|---|---|
| I (NA) | 1.5 | 2.2 | 1.9 | 7,050 |
| II (SU/EE) | 8.8 | 5.4 | 6.7 | 2,560 |
| III (WE/JANZ) | 3.9 | 4.1 | 4.0 | 4,260 |
| IV (LA) | 2.1 | 3.4 | 2.9 | 1,070 |
| V (Af/SEA) | 1.8 | 2.9 | 2.5 | 240 |
| VI (ME/NAf) | 4.3 | 6.6 | 5.7 | 1,430 |
| VII (C/CPA) | 6.3 | 4.3 | 5.1 | 350 |
| World | 3.1 | 3.1 | 3.1 | 1,565 |

We chose to make two projections of economic growth to the year 2030. GDP is the single most important determinant of energy use and its future values are somewhat uncertain. Having a range of values in our projections, therefore, allowed us to examine the linkage of many variables to GDP. We examined in detail a High and a Low economic projection. Neither the High nor the Low was intended to represent a prediction, forecast, or even best guess. But an attempt was made to span a sufficiently wide range of values so that expected values would be included.

For making these projections, we relied on the projections and results of other similar recent studies including those of WAES (1977) and WEC (1978). Our projections differ from these in that we lowered economic growth, and consequently energy demand, so that energy supply and demand would balance given a "reasonable" energy supply situation. A central guidance for extending our projections to the year 2030 and for developing the two scenarios in greater detail was the constant checking for internal consistency and consistency among world regions. Even though the application of these guidelines is judgmental, we found that the procedure was very useful for eliminating potential scenario values that on the surface might appear reasonable. Achievement of consistency within a scenario at any level of detail is clearly only a necessary condition for reasonableness and not a sufficient condition.

As part of the exercise of setting economic projections, therefore, there were several iterations of making assumptions, analyzing implications, checking for consistency and making refinements of assumptions. The projections presented here are the result of this process and we will not dwell on the intermediary values.

Our two projections for the growth rate of regional gross domestic product are given in Table 6. The general trend in these projections which is exhibited in all regions is the

TABLE 6 Scenario definition part 2: Growth rates of GDP by region High and Low scenarios (percent/year).

| Region | 1975–1985 | 1985–2000 | 2000–2015 | 2015–2030 |
|---|---|---|---|---|
| | *High scenario* | | | |
| I (NA) | 4.3 | 3.3 | 2.4 | 2.0 |
| II (SU/EE) | 5.0 | 4.0 | 3.5 | 3.5 |
| III (WE/JANZ) | 4.3 | 3.4 | 2.5 | 2.0 |
| IV (LA) | 6.2 | 4.9 | 3.7 | 3.3 |
| V (Af/SEA) | 5.8 | 4.8 | 3.8 | 3.4 |
| VI (ME/NAf) | 7.2 | 5.9 | 4.2 | 3.8 |
| VII (C/CPA) | 5.0 | 4.0 | 3.5 | 3.0 |
| World | 4.7 | 3.8 | 3.0 | 2.7 |
| | *Low scenario* | | | |
| I (NA) | 3.1 | 2.0 | 1.1 | 1.0 |
| II (SU/EE) | 4.5 | 3.5 | 2.5 | 2.0 |
| III (WE/JANZ) | 3.1 | 2.1 | 1.5 | 1.2 |
| IV (LA) | 4.7 | 3.6 | 3.0 | 3.0 |
| V (Af/SEA) | 4.8 | 3.6 | 2.8 | 2.4 |
| VI (ME/NAf) | 5.6 | 4.6 | 2.7 | 2.1 |
| VII (C/CPA) | 3.3 | 3.0 | 2.5 | 2.0 |
| World | 3.6 | 2.7 | 1.9 | 1.7 |

ever-decreasing growth rates in later and later periods. We believe that many factors will contribute to this trend but the two most important factors are decreases in population growth rates and the increasing scarcity of basic resources. Decreases in population growth rates in our projections have already been indicated in 2.1.1. As shown by the growth rates of GDP per capita in Table 7, however, the general trend of decreasing growth rates is still evident in these projections. This decline in per-capita growth rates is attributed mainly to the depletion of resources and the concomitant increase in real cost of these resources. In our studies this factor is most evident with respect to energy resources, but other basic resources are expected to follow a similar pattern.

We have not examined the interregional trade implications of these regional economic projections. We have made the assumption, however, that because of the dependency of

TABLE 7 Per capita GDP growth rates for two scenarios to 2030 (percent/year).

| Region | High scenario 1975–2000 | 2000–2030 | Low scenario 1975–2000 | 2000–2030 |
|---|---|---|---|---|
| I (NA) | 2.9 | 1.9 | 1.7 | 0.7 |
| II (SU/EE) | 3.6 | 3.2 | 3.1 | 1.9 |
| III (WE/JANZ) | 3.0 | 1.8 | 1.7 | 0.9 |
| IV (LA) | 3.0 | 2.4 | 1.6 | 1.9 |
| V (Af/SEA) | 2.8 | 2.4 | 1.7 | 1.4 |
| VI (ME/NAf) | 3.8 | 2.8 | 2.4 | 1.2 |
| VII (C/CPA) | 2.8 | 2.4 | 1.6 | 1.4 |
| World | 2.4 | 1.9 | 1.3 | 0.9 |

the developing regions on trade with the developed regions as a major stimulant for growth, the developing economies will be limited in their growth potential to one or two percentage points greater than the growth rates of the developed economies. This assumption has been used in some World Bank studies, in particular in a contribution to the WAES study. (See also Hicks et al. 1976.) This interregional linkage of economic growth rates is not universal and may prove unfounded for our projection period, but we have made the projections based on this assumption. Some countries, notably those of the Middle East in Region VI, are assumed not to be limited by this linkage but rather by their capability to absorb the favorable trade balances due to large oil exports.

Although these aggregate projections of population and GDP by region are the principal determinants of our energy projections, both of these projections must be divided into more detailed components for making the energy projections. For GDP in particular, the five sectors agriculture, mining, manufacturing, construction, and services are projected separately and manufacturing is further disaggregated into four subsectors depending upon energy intensity (Energy Program Group 1981, Lapillonne 1978). As an example of the differences in GDP formation in various regions for 1975 and as projected for our study period, Table 8 gives the shares of agriculture, industry (which comprises mining, manufacturing, construction, and energy) and service sectors for all regions except Region VII for which this detailed approach was not used. These sector shares, also illustrated in Figure 4, show that developing region economies are much more agriculture based than developed regions but that this share is projected to decrease markedly by 2030. The industry sector shows a greater share of GDP in the developed regions but is decreasing in time whereas the developing regions begin from a relatively low share in industry and increase in time as economic development progresses.

### *2.1.3 Energy Projections*

Detailed energy projections were made for all regions except Region VII where the general lack of data necessitated our using a more aggregated projection approach. These

TABLE 8 Shares of agriculture, industry, and services for six regions (percent GDP).

| Region | 1975 | High scenario 2000 | High scenario 2030 | Low scenario 2000 | Low scenario 2030 |
|---|---|---|---|---|---|
| *Agriculture* | | | | | |
| I (NA) | 3 | 2 | 1 | 2 | 2 |
| II (SU/EE) | 11 | 7 | 4 | 9 | 7 |
| III (WE/JANZ) | 6 | 5 | 3 | 4 | 3 |
| IV (LA) | 12 | 8 | 5 | 10 | 7 |
| V (Af/SEA) | 36 | 26 | 16 | 30 | 23 |
| VI (ME/NAf) | 7 | 4 | 2 | 5 | 4 |
| *Industry* | | | | | |
| I (NA) | 32 | 30 | 29 | 32 | 32 |
| II (SU/EE) | 50 | 46 | 41 | 46 | 43 |
| III (WE/JANZ) | 46 | 43 | 39 | 44 | 42 |
| IV (LA) | 36 | 42 | 47 | 40 | 43 |
| V (Af/SEA) | 26 | 32 | 38 | 30 | 35 |
| VI (ME/NAf) | 66 | 57 | 47 | 54 | 54 |
| *Service* | | | | | |
| I (NA) | 65 | 68 | 70 | 66 | 66 |
| II (SU/EE) | 39 | 47 | 55 | 45 | 50 |
| III (WE/JANZ) | 48 | 52 | 58 | 52 | 55 |
| IV (LA) | 52 | 50 | 48 | 50 | 50 |
| V (Af/SEA) | 38 | 42 | 46 | 40 | 42 |
| VI (ME/NAf) | 27 | 39 | 51 | 41 | 42 |

projections were made using the population and GDP projections as basic inputs, and are reported in detail separately (Energy Program Group 1981, Khan and Hölzl 1981, Chant 1981). Many further assumptions were made to provide more detail for these scenarios and the resulting projections are for final (or delivered) energy for each of the GDP sectors as well as transportation, households, and nonenergy feedstocks. These projections are given in some detail in Appendix A (Tables A.11 and A.12). Table 9 shows the growth rates in per-capita final energy for the historical period 1950–1975 and for the projection period to 2030. As is clear in this table, the projections call for much greater increases in use of energy in the developing regions than in the developed regions even on a per-capita basis.

These projections for final energy requirements were given by fuel type as input to an optimizing energy supply model (Energy Program Group 1981). This model determined the minimum cost energy supply strategy for each region taking account of energy resource costs and production constraints, new technology maximum buildup rates and energy import availabilities. The results which we use here are the requirements for primary energy for each region. These are given in some detail in Appendix A (Tables A. 7 and A. 9) and are summarized in Table 10. The trends in per-capita primary energy use for the High scenario are shown in Figure 5 for the historical period 1950–1975 as well as for the projection period.

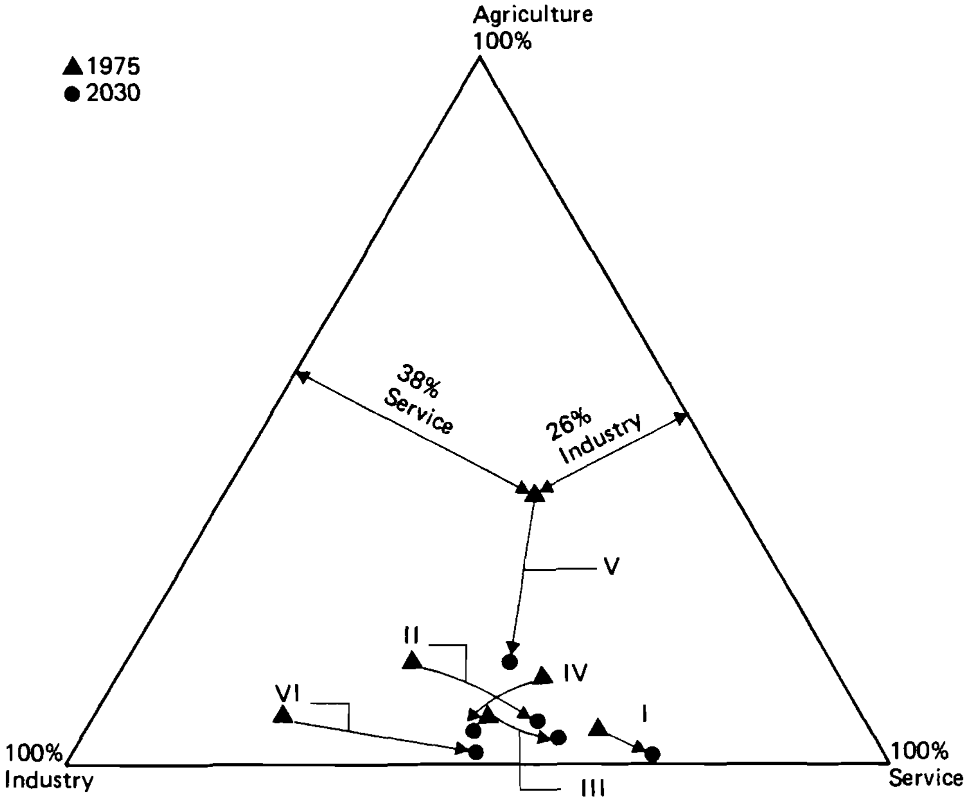



FIGURE 4 Sectoral evolution of GDP by region, High scenario.

TABLE 9 Final energy[a] per capita 1975 and growth rates: historical and two scenarios to 2030.

| Region | Growth rate (percent/year) 1950–1975 | Final energy per capita (kW/cap) 1975 | Growth rate of FE per capita (percent/year) High scenario 1975–2000 | High scenario 2000–2030 | Low scenario 1975–2000 | Low scenario 2000–2030 |
|---|---|---|---|---|---|---|
| I (NA) | 1.3 | 7.89 | 0.6 | 0.8 | 0.03 | 0.2 |
| II (SU/EE) | 3.9 | 3.52 | 1.8 | 1.5 | 1.4 | 0.7 |
| III (WE/JANZ) | 3.3 | 2.84 | 1.8 | 0.8 | 0.8 | 0.3 |
| IV (LA) | 4.0 | 0.80 | 3.2 | 2.2 | 1.9 | 1.6 |
| V (Af/SEA) | 4.3 | 0.18 | 3.5 | 2.6 | 2.3 | 1.7 |
| VI (ME/NAf) | 7.4 | 0.80 | 4.4 | 2.3 | 3.2 | 1.1 |
| VII (C/CPA) | 9.0 | 0.43 | 3.1 | 2.3 | 1.6 | 1.3 |
| World | 2.4 | 1.46 | 1.2 | 1.2 | 0.3 | 0.5 |

[a]Total final energy including nonenergy feedstocks but excluding noncommercial sources of energy (wood, animal waste, etc.).

TABLE 10 Summary of scenario energy projections: primary energy[a].

Primary energy for 1950, 1975, and projections to 2030 for the High and Low scenarios, by region (TW).

| | Historical | | High scenario | | Low scenario | |
|---|---|---|---|---|---|---|
| Region | 1950 | 1975 | 2000 | 2030 | 2000 | 2030 |
| I (NA) | 1.14 | 2.65 | 3.89 | 6.02 | 3.31 | 4.37 |
| II (SU/EE) | 0.42 | 1.84 | 3.69 | 7.33 | 3.31 | 5.00 |
| III (WE/JANZ) | 0.67 | 2.26 | 4.29 | 7.14 | 3.39 | 4.54 |
| IV (LA) | 0.06 | 0.34 | 1.34 | 3.68 | 0.97 | 2.31 |
| V (Af/SEA) | 0.06 | 0.33 | 1.43 | 4.65 | 1.07 | 2.66 |
| VI (ME/NAf) | 0.01 | 0.13 | 0.77 | 2.38 | 0.56 | 1.23 |
| VII (C/CPA) | 0.03 | 0.46 | 1.44 | 4.46 | 0.98 | 2.29 |
| World | 2.39 | 8.21[b] | 16.8 | 35.7 | 13.6 | 22.4 |

Primary energy growth rates for 1950–1975 and projections to 2030 for the High and Low scenarios, by region (percent/year).

| | Historical | High scenario | | Low scenario | |
|---|---|---|---|---|---|
| Region | 1950–1975 | 1975–2000 | 2000–2030 | 1975–2000 | 2000–2030 |
| I (NA) | 3.4 | 1.5 | 1.5 | 0.9 | 0.9 |
| II (SU/EE) | 6.1 | 2.8 | 2.3 | 2.4 | 1.4 |
| III (WE/JANZ) | 5.0 | 2.6 | 1.7 | 1.6 | 1.0 |
| IV (LA) | 7.1 | 5.7 | 3.4 | 4.3 | 2.9 |
| V (Af/SEA) | 7.1 | 6.1 | 4.0 | 4.8 | 3.1 |
| VI (ME/NAf) | 10.7 | 7.5 | 3.9 | 6.2 | 2.6 |
| VII (C/CPA) | 11.1 | 4.7 | 3.8 | 3.1 | 2.9 |
| World | 5.1 | 2.9 | 2.5 | 2.0 | 1.7 |

[a]Including nonenergy feedstocks but excluding noncommercial energy.
[b]Including 0.21 TW for bunkers.

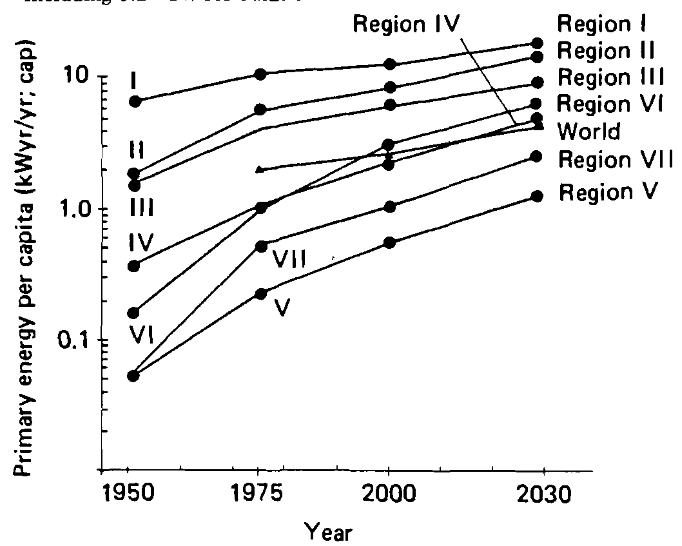



FIGURE 5 Primary energy per capita by region, 1950–2030, High scenario.

## 2.2 Energy–Economy Linkage in the Aggregate

The objective of the analysis that is reported here is not to develop scenarios but to interpret the linkage between the economic variables and the associated energy usage projections *in an economic sense*. In so doing, we gain insight into the nature of this linkage that was postulated in noneconomic terms and we can interpret projected relative changes in terms of elasticities involving GDP, energy prices, and substitution of nonenergy inputs for energy. We begin this analysis by examining the energy–economy linkage at the most aggregated level.

### *2.2.1 Energy–GDP Ratios and Elasticities*

One simple way to examine the linkage between energy and GDP is to calculate the ratio of energy consumption to GDP. Using the data from Appendix A for primary energy and GDP, both historical and projected, we can plot primary energy per unit GDP versus GDP per capita as shown in Figure 6. The abscissa (GDP per capita) in this plot is an aggregate measure of economic development, thus the graph indicates the changing energy intensity of economies as they develop. The developing regions exhibit a trend of increasing energy usage per unit of GDP as their economies have developed between 1950 and 1975 and this trend continues in our projections, although less severely. The developed regions, in general, surpassed the point where energy intensity is increasing and are on a downward

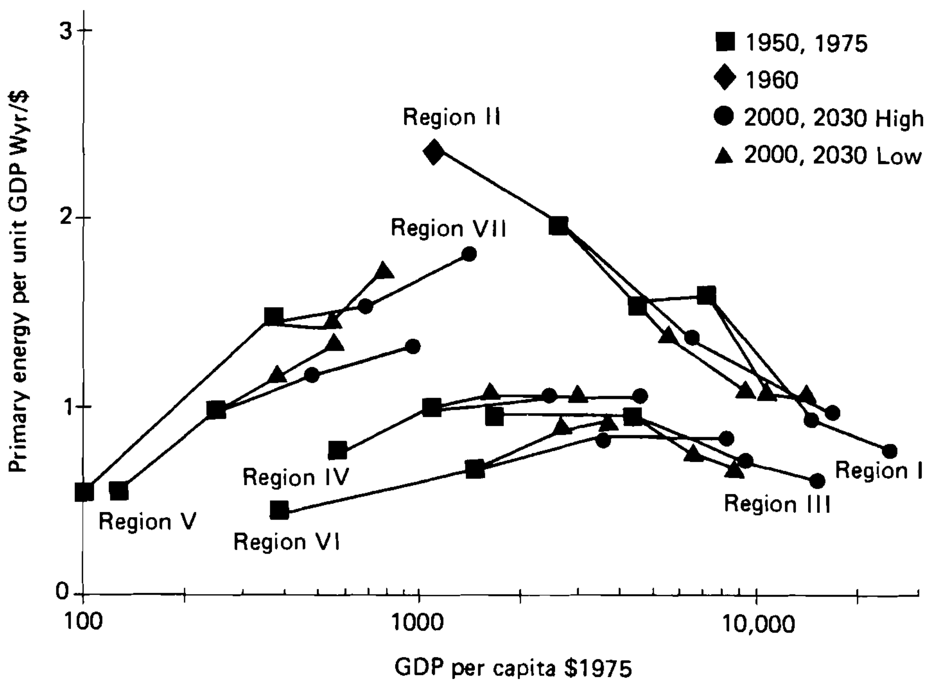



FIGURE 6 Primary energy per unit GDP versus GDP per capita. Historical (1950–1975) and scenario projections to 2030.

trend in the projections. The points plotted for 2030 in all regions except Regions IV and VI indicate more primary energy consumption than the trend would indicate (especially for Regions I and VII) because in these regions the supply strategy includes large amounts of coal liquefaction. This technology for satisfying the requirements for liquid fuel involves 40 percent losses in conversion from coal to liquid fuel and consequently requires higher levels of primary energy.

Another simple way to examine the linkage between energy and GDP is to relate primary energy per capita to GDP per capita. As an example of this relationship over a long historical period, Figure 7 presents a graph of primary energy per capita versus GDP per capita (in constant dollars) for the USA, for the period 1910–1978. Even though the annual variations as shown in this figure are both increases and decreases, the long-term trend is unmistakable. And, of course, in our scenario projections to the year 2030 it is the long-term trends that interest us rather than the annual fluctuations.

If we change the scale of the graph of Figure 7, replace the detailed curve between 1910 and 1978 by a straight line, and correct for the addition of Canada we obtain the historical period part of Figure 8. This second figure now has the primary energy and GDP projections to the year 2030 added for both the High and Low scenarios for Region I. The change in slope between the historical period and the scenario projections is immediately apparent. It is the purpose of this analysis to examine the nature of this change in detail for all regions. What may be pointed out immediately is that, especially for Region I, our scenario projections include large effects of energy conservation and efficiency improvements over and above what has occurred in the past.

There are two points shown on Figure 8 which require further comment. The actual scenario projections and energy supply strategies for Region I, lead to large increases in

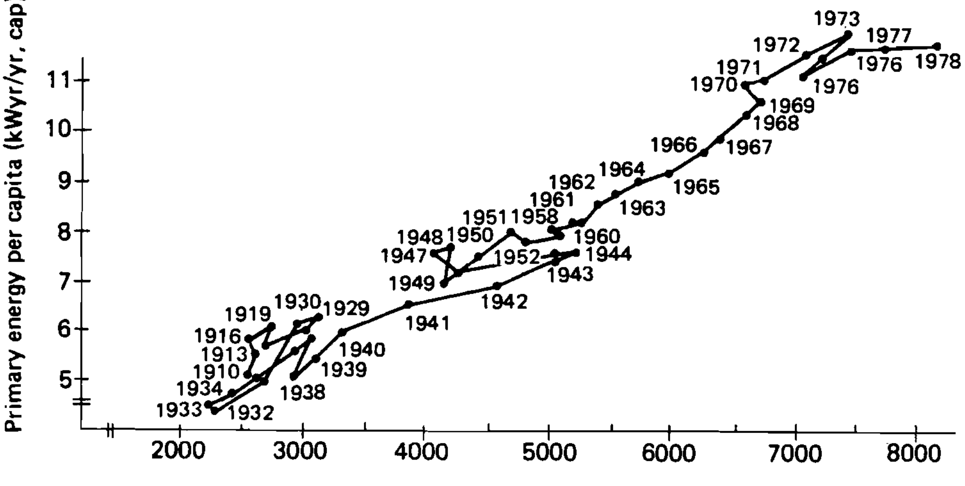



FIGURE 7 Primary energy and GDP per capita, USA, 1910–1978.
NOTE: For 1910–1929 and 1951–1959 three-year averages are shown in order to reduce the confusion of point clusters.
SOURCE: Based on data from Alterman (1977) and Bureau of the Census (1978).

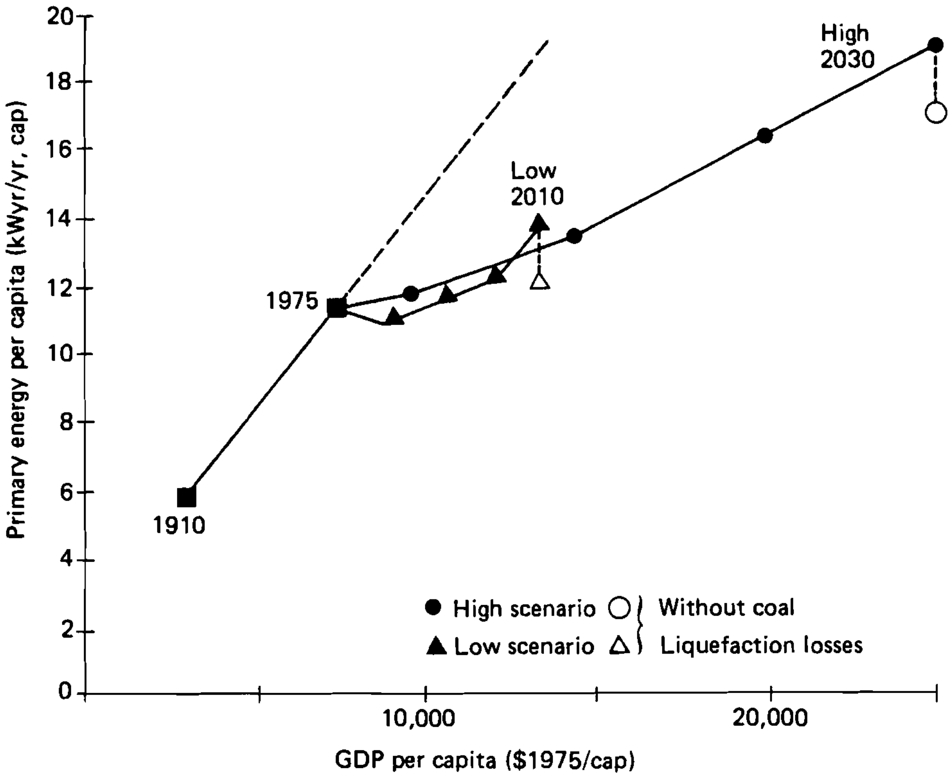



FIGURE 8 Primary energy and GDP per capita, Region I, 1910–2030.

primary energy consumption between 2015–2030. As mentioned earlier, this is due in large part to the necessity of using coal liquefaction with large losses as a supply technology for liquid fuel demand. If these losses are subtracted from the 2030 primary energy consumption in Region I, the corresponding energy consumption drops significantly. This brings the 2030 Low scenario point onto the projected long-term trend line and drops the 2030 High scenario point below this line.

This trend of conservation and increasing efficiency of energy use is projected for all regions but to different and lesser extents than for Region I. Figure 9, using a logarithmic scale, shows these trends for all regions. The historical period is limited to 1950–1975 but the long-term trend evident in the projections is clear.

Perhaps the simplest way to quantify this changing long-term trend between energy use and GDP is to calculate the energy–GDP elasticity. This elasticity $\epsilon$ is defined by the following equation:

$$\frac{E(t_2)}{E(t_1)} = \left[\frac{\mathrm{GDP}(t_2)}{\mathrm{GDP}(t_1)}\right]^{\epsilon} \tag{1}$$

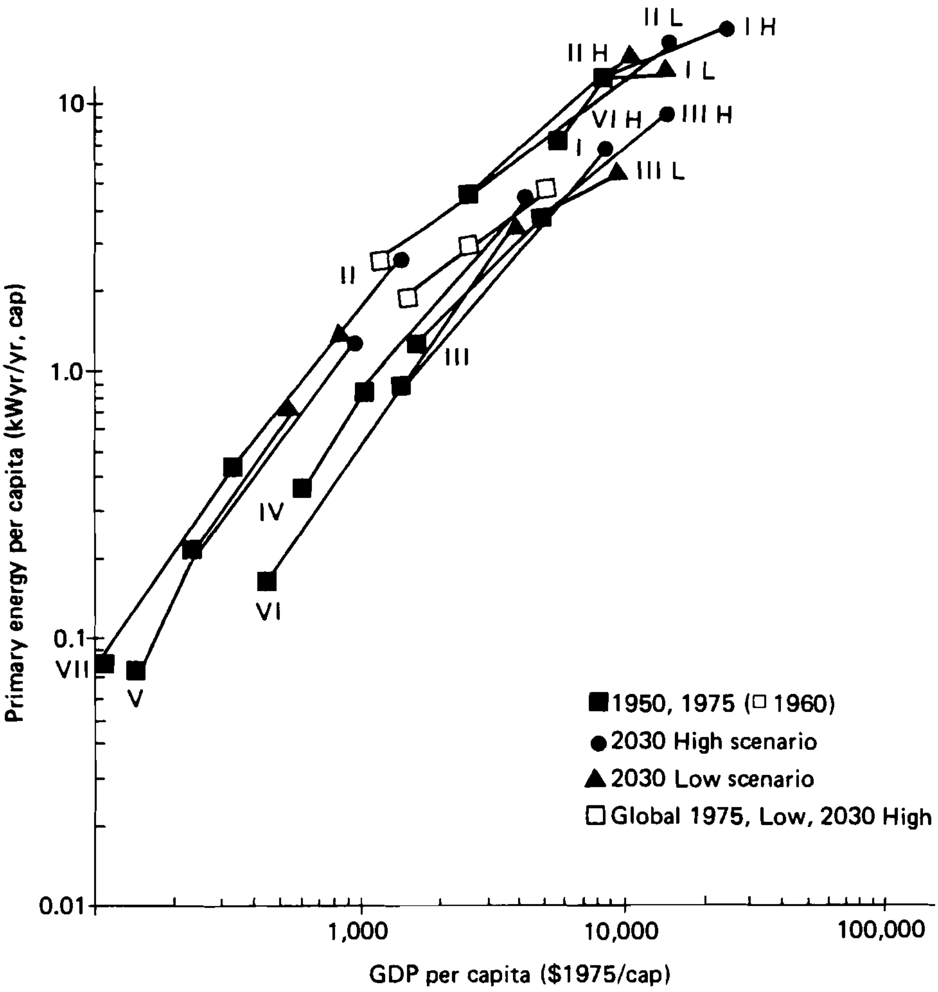



FIGURE 9 Primary energy and GDP per capita, IIASA regions, 1950–2030.

where $t_1$ and $t_2$ are two points in time, $E$ represents energy consumption (which can be either primary or final in our applications) and GDP is in real terms. With this definition, the elasticity $\epsilon$ is the average (constant) value for the time period from $t_1$ to $t_2$. For small changes in energy use and GDP over a short period, say one year, this parameter can be interpreted simply as the ratio of the percentage change in energy to the percentage change in GDP.

Analyses of historical data indicate that values of $\epsilon$ less than unity are common for developed economies where increases in GDP are associated with somewhat smaller (in percentage terms) increases in energy consumption. This result can be interpreted as increases in the efficiency of the use of energy or in changes in the nature of GDP such that less energy-intensive sectors gain a larger share of total GDP. For developing economies, the values of this elasticity are typically greater than unity such that GDP increases are associated with greater than commensurate increases in energy consumption. Usually this result does not imply a decrease of efficiency but a rapidly changing economy that is increasing the share of industry and mechanization of agriculture at the expense of more traditional techniques.

Primary energy–GDP elasticities $\epsilon_p$ are given for all seven regions in Table 11 for the historical period 1950–1975 and for the projection period 1975–2030 for both scenarios. For the historical period, these parameters were determined by fitting a straight line to the logarithmic transformation of eqn. (1), using the 5-yearly data given in Appendix A. For the projection period, since no data smoothing was necessary, only the period end points are required to calculate the elasticities.

TABLE 11 Primary energy–GDP elasticities $\epsilon_p$ 1950–2030.

| Region | Historical[a] 1950–1975 | High scenario 1975–2000 | High scenario 2000–2030 | Low scenario 1975–2000 | Low scenario 2000–2030 |
|---|---|---|---|---|---|
| I (NA) | 1.03 | 0.42 | 0.67 | 0.36 | 0.89[b] |
| II (SU/EE) | 0.77 | 0.65 | 0.67 | 0.62 | 0.62 |
| III (WE/JANZ) | 0.96 | 0.70 | 0.77 | 0.65 | 0.73 |
| IV (LA) | 1.28 | 1.04 | 0.98 | 1.06 | 0.97 |
| V (Af/SEA) | 1.52 | 1.15 | 1.11 | 1.18 | 1.19 |
| VI (ME/NAf) | 1.20 | 1.16 | 0.96 | 1.23 | 1.10 |
| VII (C/CPA) | 1.57 | 1.06 | 1.17 | 0.98 | 1.27[b] |
| World | 0.99 | 0.70 | 0.90 | 0.67 | 0.93 |

[a] Historical values were computed by linear regression on logarithmic transformation of eqn. (1) using 5-yearly data. Values for the projection period result from the scenario data.

[b] The primary energy–GDP elasticity is unusually high for Regions I and VII in the Low scenario because of coal liquefaction losses (see page 20). If these losses are subtracted from primary energy consumption in 2030, the resulting elasticities are 0.53 and 0.94 for Regions I and VII respectively. The same effect is present in the High scenario for Regions I, II, III and VII but is less pronounced in the elasticity because GDP growth is higher.

The elasticities for the historical period follow the well-observed trend of being lesss than unity for developed economies and greater than unity for developing economies. Regions V and VII exhibit the largest value of $\epsilon_p$ for the historical period but these average values mask an apparent trend from even higher values at the beginning to lower values near the end of this period.

For the projection period, the developing regions continue the trend of decreasing elasticities as the economies become more developed and approach the unity value. Region VII is a notable exception to this trend, but as we have pointed out before this is again evidence of the coal liquefaction losses in that region. Indeed, the elasticity for Region I, Low scenario 2000–2030 reflects this same effect most visibly because the GDP growth projection is very small for that time period so that any increase in primary energy consumption yields an unusually high value for the primary energy–GDP elasticity.

These energy–GDP elasticities can be calculated with respect to final energy eliminating the unusual effects near 2030 due to large amounts of coal liquefaction. Table 12

TABLE 12 Final Energy–GDP Elasticities $\epsilon_f$ 1950–2030.

| Region | Historical[a] | High scenario | | | | Low scenario | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1950–1975 | 1975–1985 | 1985–2000 | 2000–2015 | 2015–2030 | 1975–1985 | 1985–2000 | 2000–2015 | 2015–2030 |
| I (NA) | 0.84 | 0.31 | 0.43 | 0.53 | 0.48 | 0.24 | 0.38 | 0.53 | 0.46 |
| II (SU/EE) | 0.68 | 0.59 | 0.58 | 0.52 | 0.53 | 0.54 | 0.57 | 0.50 | 0.41 |
| III (WE/JANZ) | 0.84 | 0.77 | 0.65 | 0.58 | 0.51 | 0.67 | 0.64 | 0.60 | 0.49 |
| IV (LA) | 1.21 | 1.07 | 1.01 | 0.97 | 0.90 | 1.10 | 1.03 | 0.95 | 0.88 |
| V (Af/SEA) | 1.42 | 1.20 | 1.08 | 1.05 | 1.01 | 1.19 | 1.12 | 1.14 | 1.06 |
| VI (ME/NAf) | 1.17 | 1.12 | 1.07 | 0.95 | 0.81 | 1.21 | 1.11 | 1.01 | 0.93 |
| VII (C/CPA) | 1.53 | 1.10 | 1.02 | 1.02 | 0.96 | 1.02 | 0.98 | 0.99 | 0.90 |
| World | 0.87 | 0.69 | 0.73 | 0.78 | 0.77 | 0.64 | 0.73 | 0.79 | 0.74 |

[a] See footnote *a*, Table 11.

gives these elasticities for the historical period 1950–1975 and for four periods during the projection period 1975–2030. The trend of decreasing elasticities as economies develop (both developed and developing economies) is now quite clear. The only exception is Region I which has very low values for the initial years of the projection period. This results from our assumptions that Region I has a great conservation potential that it can and will take advantage of as rapidly as possible. A large part of this conservation before 2000 is due to fuel efficiency improvements in automobiles which have been mandated in the USA and Canada.

It should be noted that as the primary energy–GDP elasticities are biased upward because of coal liquefaction losses, the final energy–GDP elasticities can be considered to be biased downward because of the increasing share of electricity in our projections. This share doubles in most regions between 1975 and 2030, increasing from 12.5 percent to 24–25 percent in Regions I and III, from 9 percent to 20–21 percent in Region II, and from 6 percent to 12 percent in developing regions. (See Table A.13 of Appendix A.)

### *2.2.2 Income and Price Elasticities*

The analyses reported here are at a very aggregate level. It is recognized that there are many factors which determine the relationship between energy consumption and economic growth. One of the factors that tends to make energy growth smaller than economic growth is technological development. Another factor is the changing nature of economic activity that, for developed economies, is usually away from energy-intensive industry toward services; and for developing economies, is away from low energy-consuming agriculture toward energy-intensive industry. These two factors can, in the aggregate, explain the energy–GDP relationships noted in 2.2.1.

Energy consumption is also affected by price. It is instructive to separate these two effects for the projection period when we expect price increases to play an important role in determining energy consumption. The two factors mentioned above (technological development and changing texture of GDP) and others that depend upon GDP we call the *income effect*.* Factors that are related to price we call the *price effect*.* The separation of energy demand into these two effects is very useful but, of course, in application can be somewhat arbitrary. For example, the mandated motor vehicle efficiency improvement in Region I is not exactly an income or price effect but is an important factor affecting projected energy consumption for this region.

The income effect relates changes in energy consumption to changes in GDP when there is no price change and is measured by the energy–income elasticity $\gamma$. The price effect relates changes in energy consumption to changes in energy price when there is no change in GDP and is measured by the energy–price elasticity $\beta$. These relationships are formalized by the equation:

$$\frac{E(t_2)}{E(t_1)} = \left[\frac{\mathrm{GDP}(t_2)}{\mathrm{GDP}(t_1)}\right]^{\gamma} \left[\frac{P(t_2)}{P(t_1)}\right]^{\beta} \tag{2}$$

*These definitions should not be confused with those in traditional economics where a price effect is divided into a substitution effect and an income effect.

where, in addition to the variables of eqn. (1), $P(t)$ is the appropriate price of energy (in real terms) that applies at time $t$. (Prices are discussed in detail below.) For periods when there are no changes in the price of energy then the energy–income elasticity $\gamma$ is exactly the same as the energy–GDP elasticity $\epsilon$. As with the elasticity $\epsilon$, the elasticities $\gamma$ and $\beta$ may be defined for either primary energy or final energy.

In the application of eqn. (2), we examine the scenario data for GDP and final energy for the entire projection period 1975–2030, thus defining $t_1$ as 1975 and $t_2$ as 2030. Since the data for energy and GDP are given, then once the appropriate price increase is specified, eqn. (2) defines a linear relationship between $\gamma$ and $\beta$ as follows:

$$\beta = \frac{\log E_r}{\log P_r} - \gamma \frac{\log \mathrm{GDP}_r}{\log P_r} \qquad (3)$$

where the subscript $r$ denotes the value of the variable relative to the base year value. The GDP and final energy data are given in Appendix A, Tables A.3 and A.11 for each region and the relative price increase assumptions are discussed below.

*Energy Prices*

It should be immediately clear that the energy price that is appropriate for eqn. (2) is *not* the international price of crude oil even though this is the price often quoted when energy price increases are referred to. If energy price is to help explain the consumption of energy then the price must be the price to the *user* and must be quoted in real terms or in relation to other prices. Thus we specify the energy price for final (delivered) energy, averaged over all forms of final energy, and we specify real price increases relative to a base year value.

Before specifying the relative price increases that will be used for interpreting the scenario projections, it is useful to look at recent energy prices. Gathering, reconciling, and aggregating price data for (delivered) final energy products is a tremendous task even for one country. There is a multiplicity of energy products at the user level, and even the same product is sold at vastly different prices to different users.

What can be done is to select important representative energy commodities and gather price data on these according to aggregate user categories. At a minimum, petroleum products used for transportation should be separated because of the large taxes that are usually levied on these products. Also the user categories of the industry sector and of the residential and commercial sector should be separated because the typically large energy users in industry pay a lower unit price for energy. Prices for different years must be adjusted for inflation. Data for different fuel types within these user categories can be aggregated on a calorific quantity basis, but one must recognize that this procedure is not ideal because of different end use efficiencies, environmental effects, ease of use, and the like. The user categories can also be aggregated on the calorific quantity basis with the same caveat. Finally, data for countries within a geographic region can be aggregated on the same basis after choosing an appropriate measure of the equivalences of different national currencies.

This procedure was followed by Hogan (1980) to produce the data of Table 13. For Region I in 1972, for example, the delivered energy prices varied significantly for the three

TABLE 13 Real prices for final (delivered) energy (1975 $ per kWyr).

| | Industry sector | Transport sector | Residential-commercial sector | All sector aggregate |
|---|---|---|---|---|
| Region I (NA) | | | | |
| 1972 | 30 | 116 | 83 | 70 |
| 1975 | 52 | 144 | 108 | 97 |
| 1975–1972 | 1.73 | 1.24 | 1.30 | 1.35 |
| Region III (WE/JANZ) | | | | |
| 1972 | 62 | 254 | 135 | 113 |
| 1975 | 92 | 338 | 174 | 159 |
| 1975–1972 | 1.48 | 1.33 | 1.29 | 1.41 |

NOTE: $100 per kWyr is equivalent to $19.40 per barrel of oil equivalent, $3.34 per million Btu, and $0.011 per kWhr. These prices are calculated from data contained in Hogan 1980. Data on current prices were adjusted for inflation using a GNP deflator; currency conversions were based on a purchasing power parity conversion rate. The data reported here for Region III are for the aggregation of data for the four largest energy-using countries only: France, FRG, the UK, and Japan.

user categories, with the transport sector prices ($116/kWyr)* being almost four times the industry sector prices ($30/kWyr). For the all sector aggregate price, Region III prices were approximately 60 percent higher than Region I. Also, on average, 1975 delivered energy prices were only about 40 percent greater (in real terms) than 1972 prices in either region. Clearly, the international price of crude petroleum increased by a much greater factor during this same 3-year period, even in real terms, but crude petroleum prices are not the only prices of interest in analyzing the user demand for energy.

Hogan aggregated fuel types within sectors and across sectors using a Cobb-Douglas function formulation to estimate another average energy price. His procedure assumed that interfuel substitutions would occur to take advantage of different relative fuel price increases. His average price index indicated that 1975 prices would be only 22 percent higher than 1972 prices for the USA and Canada and that price increases in other countries would be as follows: France, 11 percent; the FRG, 15 percent; the UK, 33 percent; and Japan, 31 percent.

The conclusion is that real prices to the user for delivered energy had not increased by more than 40 percent between 1972 and 1975, on average, and possibly less depending on aggregation methods.

*Energy Price Projections*

Energy price projections are required for interpreting the scenario projections in terms of income and price elasticities. The price projection required is for final energy delivered to the user and for real price increases relative to 1972 and not relative to the base year 1975, for reasons explained below.

There is a variable lag between the time a price change is made and the effect in the economy is noticed. In some situations the time lag can be zero when the activity requiring

*Prices are quoted in constant (1975) US dollars.

the energy can be immediately changed or foregone, as for example, pleasure travel. In most situations, however, the time lag is very long, up to two or three decades before industrial processes can be redesigned and new equipment can be economically replaced. Even though the price increases of 1973 and 1974 have had a noticeable effect in some categories of energy consumption by 1975, we assume that a negligible part of the ultimate reaction to these price increases had yet occurred by 1975. Thus, since energy consumption will still be reacting to these earlier price increases, we must include these price increases in our definition of relative price appropriate for eqn. (2). The lagged effect of later price increases is accounted for by assuming that the actual relative price increases for energy will be in existence by approximately 2010 so that their full effect will be represented in the scenario projections for 2030.

Having defined the appropriate energy price, we now must be specific about the magnitude of the increase to be used in our analysis. As a guideline, we begin by examining energy production cost increases that result from the optimized supply scenarios resulting from our modeling exercise (Energy Program Group 1981, Chapter 17). Production costs are not, however, the only determinant of energy prices to the user so these can be used only as a guideline, as outlined below, for establishing our scenario price increases.

For our current purposes, we use the cost data for each supply technology, the resource cost data, and the mix of technologies that define the supply strategy and calculate an average cost per unit of final energy. These costs include all resource costs including imported crude at world trade prices and all energy conversion costs for refineries, electric power plants, etc. Costs are averaged over all final energy produced so that energy losses are accounted for. For each case, the total annual cost of supply of all fuel types and electricity was calculated. This total cost was then allocated per unit of final energy that would result from this total production. Thus, for example, the cost of production of electricity was calculated for the amount of secondary energy (gross power station output) required, but this cost was divided by the net amount of final energy (electricity delivered to the user) produced. All costs downstream from the power plant or refinery – administrative costs, interest payments and profit, transmission, transportation and distribution costs, trade margins and taxes – are *not* counted in this calculation.

Production and conversion costs are shown in Table 14 for 2030 along with 1972 costs estimated using the same procedure. Average production and conversion costs would be within the range of \$101 to \$126 per kWyr of final energy for 2030 for both the High and the Low scenarios. These 2030 costs would be between 3.4 and 4.2 times the 1972 costs for Regions I and IV, and between 2.9 and 3 for Region III in both scenarios. The apparently low costs for Region II reflect very high shares of relatively inexpensive central sources of heat – district heat and cogeneration plants.

A comparison of final energy prices for 1972 from Table 13 with production and conversion costs of energy shows that in 1972 these costs comprised only 43 percent of final energy prices for Region I and 35 percent for Region III. The difference consists of taxes, downstream costs, administrative and other costs. All taxes and other costs are not likely to increase at the same rate as energy production and conversion costs; some of these other costs should not increase at all, while others will increase to varying degrees, and taxes will vary from country to country. It is simply an assumption, adopted here, that these taxes and other costs will little more than double their 1972 value. Combining these components of costs results in approximately a 3-fold increase in prices for Region I

TABLE 14 Energy production and conversion cost estimates, \$(1975) per kWyr[a] of final energy.

| Region | 1972 | High scenario 2030 | Low scenario 2030 |
|---|---|---|---|
| I (NA) | 30 | 126 | 118 |
| II (SU/EE) | ne | 108 | 103 |
| III (WE/JANZ) | 40 | 119 | 114 |
| IV (LA) | 30 | 104 | 102 |
| V (Af/SEA) | ne | 105 | 101 |

ne–not estimated.
[a] \$100 per kWyr is equivalent to \$19.40 per barrel of oil equivalent, \$3.34 per million BTU and \$0.011 per kWhr.

and a 2.4-fold increase for Region III. The lower price increase for Region III is due to the relatively high level of prices already in place in this region in 1972. Since these price levels did not prevail throughout the other regions in 1972, the relative price increase for all other regions is defined to be 3-fold.

In summary, the implied price evolutions employed in the interpretation of scenario projections in this report are as follows:

- Energy prices are for final energy (delivered to the user) averaged for all fuels on a calorific content basis.
- Energy prices are for real increases relative to 1972.
- Energy prices are projected to increase by a factor of 2.4 for Region III and by a factor of 3 for all other regions.

*Elasticities*

For the historical period (1950–1975), real energy prices did not change significantly; they actually dropped slightly in most countries. Without taking account of these small price changes during this period, the values of the income elasticity $\gamma$ would be the same as those given in Tables 11 and 12 for the energy–GDP elasticity $\epsilon$ for primary energy and for final energy, respectively.

For the scenario projection period 1975–2030, energy prices do increase and therefore both income elasticity $\gamma$ and price elasticity $\beta$ must be considered. If the scenario projections for GDP increases and final energy increases are specified (as in Tables A.3 and A.11 in Appendix A), and if energy price increases are also specified (as above), then the corresponding combinations of $\gamma$ and $\beta$ consistent with the scenario projections can be calculated. These combinations of $\gamma$ and $\beta$ are shown in Figure 10 for the High scenario and in Figure 11 for the Low scenario. These figures apply to the all sector aggregate of GDP and final energy projections for the period 1975–2030. The grouping of the developed regions (I, II, and III) with values of $\gamma$ less than unity and of the developing regions (IV, V, VI, and VII) with values of $\gamma$ greater than unity is as expected. A comparison of the two figures for the two scenarios indicates that the High scenario has higher price elasticities or lower income elasticities than the Low scenario for all regions. This result indicates that the High scenario projections represent better assumed efficiency improvements and stronger assumed conservation effects than the Low scenario.

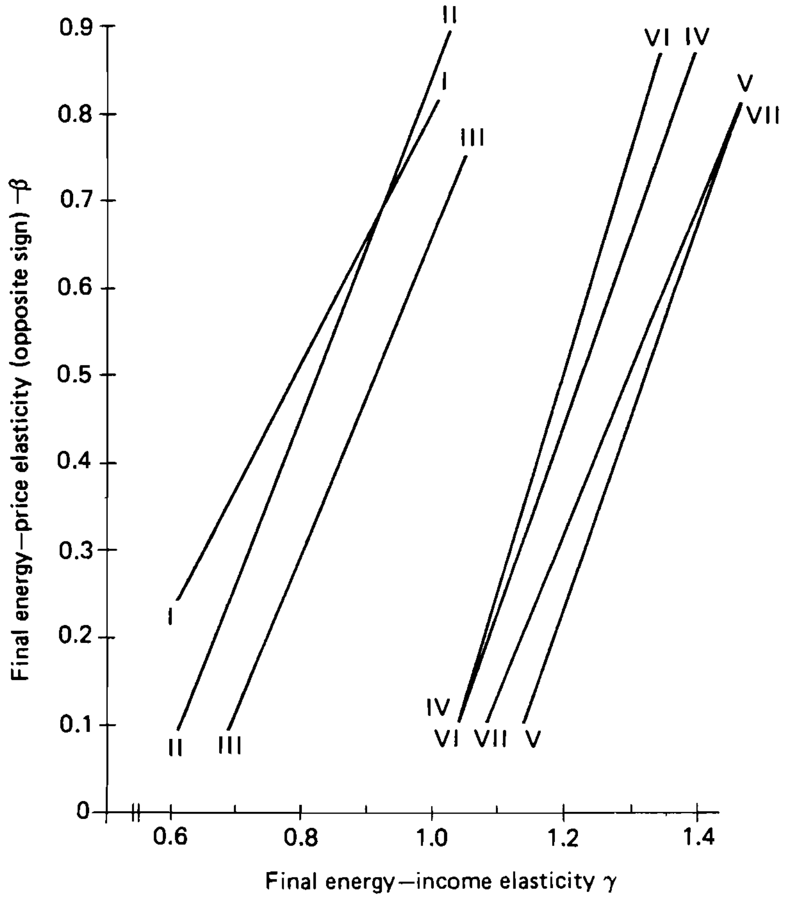



FIGURE 10 Income and price elasticities for aggregate final energy, High scenario.

Particular numerical values for $\gamma$ and $\beta$ may be selected for any region on the basis of Figures 10 and 11. For example, if the income elasticity were unity (that is, energy use increases in step with GDP increases if there were no price increase), then the price elasticities represented by the scenario projections are $-$ 0.81 and $-$ 0.52 for the High and the Low scenarios in Region I, respectively. For the historical value of the income elasticity for this region (for final energy it is 0.84), the corresponding price elasticities would be $-$ 0.58 and $-$ 0.39 for the two scenarios. Table 15 presents a range of values of both $\gamma$ and $\beta$ for all regions. As indicated in this table, the price elasticities for aggregate final energy are lower for the developing regions than for the developed regions. This result is not an irrefutable conclusion because the range of income elasticities shown was chosen arbitrarily and larger price elasticities would result if larger income elasticities were chosen. Based on the historical values of the income elasticities, however, the range of values shown seems reasonable. Accepting these ranges for $\gamma$, the associated price elasticities

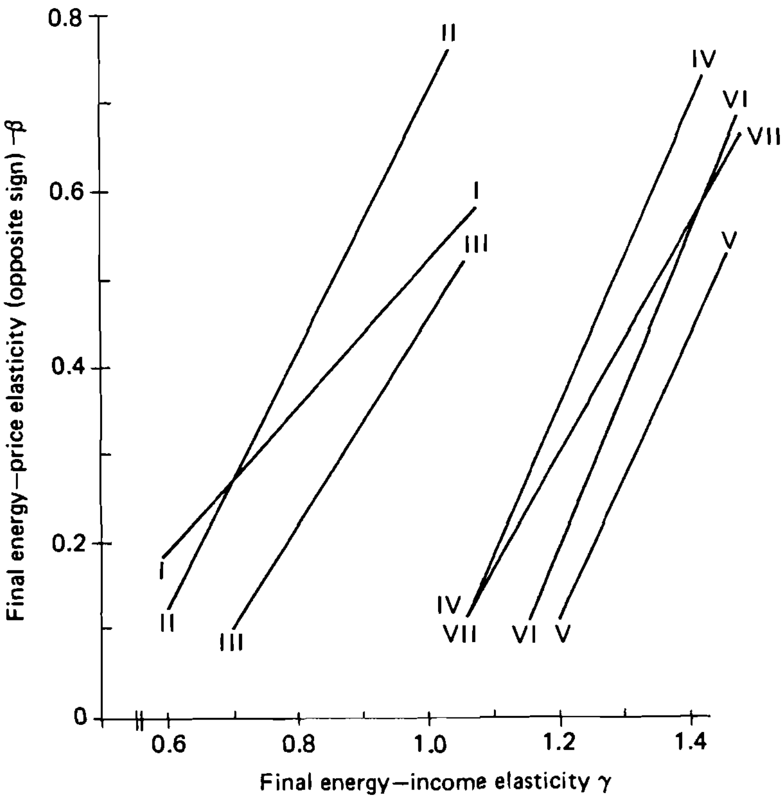



FIGURE 11 Income and price elasticities for aggregate final energy, Low scenario.

shown are evidence of strong price-induced conservation that is represented in the scenario projections. This conservation is strongest in the developed regions and in the High scenario.

*Payments for Energy*

A simple calculation demonstrates the burden that the developing countries will have as they develop their economies during a period of significant energy price increases. The projected energy consumption increases can be combined with the projected energy price increases to calculate the increases in the payments for energy. Since our price increases are relative to the 1972 price level of energy, these increases in payments must be interpreted also as increases from 1972. These increases in payments can be related to projected increases in GDP to obtain a relative measure of their magnitude.

Table 16 shows the results of these calculations. For Region I, High scenario final energy use is projected to almost double (1.96) between 1975 and 2030. Combined with a 3-fold increase in final energy prices, this implies nearly a 6-fold (5.88) increase in total payments for energy. The High scenario implies, however, a 4.75-fold increase of GDP for Region I so that energy payments would increase, in a relative sense, only 24 percent

TABLE 15 Final energy–income and energy–price elasticities.

| | High scenario | | Low scenario | |
|---|---|---|---|---|
| Region | Income elasticity $\gamma$ | Price elasticity $\beta$ | Income elasticity $\gamma$ | Price elasticity $\beta$ |
| I (NA) | (0.8, 1.0) | (−0.52, −0.81) | (0.8, 1.0) | (−0.35, −0.52) |
| II (SU/EE) | (0.8, 1.0) | (−0.46, −0.85) | (0.8, 1.0) | (−0.42, −0.71) |
| III (WE/JANZ) | (0.8, 1.0) | (−0.30, −0.66) | (0.8, 1.0) | (−0.22, −0.45) |
| IV (LA) | (1.1, 1.2) | (−0.23, −0.44) | (1.1, 1.2) | (−0.18, −0.35) |
| V (Af/SEA) | (1.2, 1.3) | (−0.24, −0.45) | (1.2, 1.3) | (−0.11, −0.27) |
| VI (ME/NAf) | (1.1, 1.2) | (−0.24, −0.49) | (1.1, 1.2) | (−0.02, −0.20) |
| VII (C/CPA) | (1.2, 1.3) | (−0.32, −0.50) | (1.2, 1.3) | (−0.30, −0.43) |

NOTE: Final energy price elasticities are all sector aggregates for the period 1975–2030, calculated according to eqn. (2) to be consistent with GDP and final energy (including feedstocks) scenario projections and with the assumed range of values for the income elasticities shown. The historical values for 1950–1975 for $\gamma$ are given in Table 12 under the assumption that real prices did not change during that period. These values are, respectively, 0.84, 0.68, and 0.84 for Regions I, II, and III and 1.21, 1.42, 1.17, and 1.53 for Regions IV, V, VI, and VII. The high values for the developing regions should not be applied to the projection period; the range shown in this table would be more appropriate.

TABLE 16 Increase in payments for energy relative to increase in GDP.

| Region | GDP projected increase | Final energy projected increase | Final energy price increase | Increase in energy payment divided by increase in GDP[a] |
|---|---|---|---|---|
| *High scenario* | | | | |
| I (NA) | 4.75 | 1.96 | 3.0 | 1.24 |
| II (SU/EE) | 8.23 | 3.25 | 3.0 | 1.18 |
| III (WE/JANZ) | 4.90 | 2.75 | 2.4 | 1.35 |
| IV (LA) | 10.50 | 10.36 | 3.0 | 2.96 |
| V (Af/SEA) | 10.26 | 12.56 | 3.0 | 3.67 |
| VI (ME/NAf) | 15.36 | 15.45 | 3.0 | 3.02 |
| VII (C/CPA) | 7.66 | 8.13 | 3.0 | 3.18 |
| *Low scenario* | | | | |
| I (NA) | 2.50 | 1.41 | 3.0 | 1.69 |
| II (SU/EE) | 5.07 | 2.31 | 3.0 | 1.37 |
| III (WE/JANZ) | 2.79 | 1.88 | 2.4 | 1.62 |
| IV (LA) | 6.56 | 6.49 | 3.0 | 2.97 |
| V (Af/SEA) | 5.87 | 7.42 | 3.0 | 3.79 |
| VI (ME/NAf) | 6.90 | 8.19 | 3.0 | 3.56 |
| VII (C/CPA) | 4.20 | 4.04 | 3.0 | 2.89 |

[a]For example, if energy use doubles and price triples by 2030, payments increase 6-fold but if GDP also increases 4-fold then this index is 6/4 = 1.50. Thus, the relative increase in energy payments is 50 percent. GDP and final energy projections are given in Appendix A.

(5.88/4.75 = 1.24). As shown in the table, the other developed regions would experience 18 percent and 35 percent increases in the High scenario or from 37 percent to 69 percent in the Low scenario. It is the developing regions, however, which exhibit astonishing relative increases of from 3-fold to almost 4-fold. Region IV, for example, would experience a 30-fold increase in energy payments while only a 10-fold increase in GDP. It would be difficult, indeed, to maintain such a growth pattern.

In this section, we have defined two scenarios of global evolution of economy and energy consumption. The linkage between the economic development and the energy consumption was defined originally in noneconomic terms, that is without using prices explicitly. We have examined this linkage in an aggregate manner in this section by looking at energy–GDP elasticities and income and price elasticities. To understand this linkage better, we now proceed to examine some of the major energy consuming sectors independently. The following section outlines the framework for analyzing these sectors and examines the household use of energy with the ($\gamma$, $\beta$) model of eqn. (2). A production function type model is then described in Section 4 which accounts for technological development and substitution of nonenergy inputs (capital and labor) for energy. This model is applied then to the nonenergy sector of the economy and to the industry sector.

## 3 SECTORAL ANALYSIS: ENERGY AS AN INPUT AND AS FINAL DEMAND

We have two objectives for examining energy use by sector. The first is to gain a better understanding of the energy–economy linkage than can be learned from aggregate analyses as in Section 2. Indeed, in our energy projections using the accounting framework of the MEDEE model, we use a detailed sectoral breakdown for determining energy use. Here we examine this projected energy demand by sector in order to understand the economic interpretation of these projections.

The second objective for sector analysis is to study the question of the shift in capital intensiveness of the economy. There are two important causes of a shift toward a more capital-intensive economy. The most readily apparent cause is the projected increased capital intensiveness in energy production. The era of readily available cheap oil and gas is over. All of the alternative forms of energy are, to varying degrees, more capital intensive. Increased electricity production whether from coal, nuclear, or solar sources is very capital intensive. The production of synthetic liquids, methanol, or hydrogen is even more capital intensive. On a long-run marginal cost basis, it is not necessary that a shift to capital-intensive production of energy implies a large increase in cost. It could be that these alternatives are just slightly higher in cost and therefore have heretofore not been implemented but now with relatively small changes in the energy sector these alternatives are attractive. Unfortunately, the current assessments of these alternatives, and particularly their costs, imply that indeed these alternatives do lead to much higher unit energy costs. It is this assessment that causes the second shift to more capital intensiveness in the economy as a whole. In sectors other than energy where energy is an important factor of production, the increase in unit cost of energy to the user will cause him to reassess his production possibilities including his use of energy and where possible shift to alternatives that use less energy. Assuming that he was operating efficiently to begin with (that is, that he cannot arbitrarily reduce his energy use and maintain production exactly as before) then shifting to processes that use less energy will necessarily use more of something else (per unit of output). This "something else", in the economy-wide analysis, must be value-added factors of production, that is, capital and labor. Thus we have the shift to more capital-intensive production of energy (a major effect in a small sector) and a second shift to more capital-intensive production in the remaining sectors of the economy due to a change in price of energy (a relatively minor effect in a very large sector).

There are two other important factors that affect the overall capital intensiveness of the developed economies. Effects similar to the one described above for energy are projected to occur in many other primary sectors of the economy. Resource extraction industries in general are experiencing the disappearance of easily accessible deposits of minerals resulting in higher exploration, development, and extraction costs, usually due to increased capital intensiveness. These costs are reflected in the prices of minerals that are used in the economy so the secondary impact in the production processes of the remaining sectors of the economy is also present. A second factor which affects the capital intensiveness of the overall economy is the development of the so-called postindustrial society. Projections for developed economies have been made that continue the recent trend of an increasing share of services and a decreasing share of industry in the economy. Since on average the service sector is less capital intensive than the industrial sector, this trend contributes to a decreasing capital–output ratio. The effects that have been mentioned above of increasing capital intensiveness in the energy, resource extraction and other industrial sectors will be off-set to a certain degree by the continual development of the postindustrial society. These sectors must be examined separately to study the question of changing capital intensiveness.

The first step in sector disaggregation is to separate the energy sector from the nonenergy sector. This separation is important when considering the changing capital intensiveness since the shifts expected in the nonenergy sector are due to the substitution effect of using relatively more nonenergy inputs in place of higher priced energy inputs, whereas in the energy sector, these shifts are due to switching to more expensive or alternative sources of energy. These two phenomena are fundamentally different and should be examined separately.

## 3.1 Framework for Two-Sector Economy

We begin with the two-sector model of an economy that separates the energy sector from the nonenergy sector. In this analysis, we define the energy sector in its broadest sense so that it includes energy resource exploration and mining as well as final energy distribution to the end user. Figure 12 depicts these two sectors in a simplified manner where each sector has its allocation of primary inputs, capital and labor, and imports are separated into energy and nonenergy commodities. There are flows of goods and services from the nonenergy sector into the energy sector that are distinguished as intermediate inputs $X_E$ and payments for taxes $T_E$.

The output of the energy sector is divided into two components. There is a final demand* for energy which we define as household energy for heating, lighting, etc. plus

*Even though the term final demand as applied to the energy sector has some connection with the term final energy, note that the two terms arise from two completely separate disciplines and should not bc confused or thought to represent the same concepts.

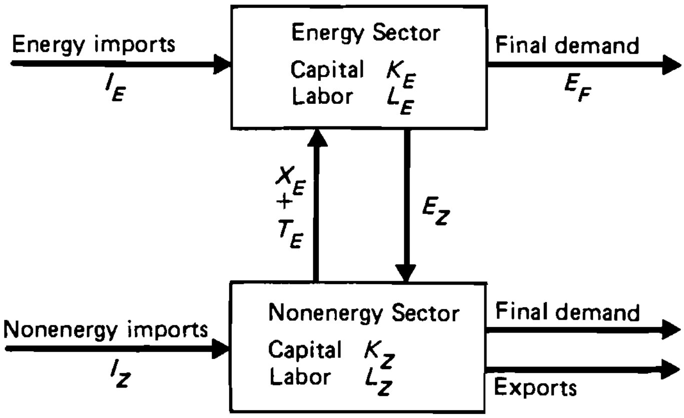



FIGURE 12 Two-sector model of an economy.

energy used for passenger transportation. The second component of energy output is used by the nonenergy sector as an intermediate input in its production process.

This same two-sector economy is depicted in Figure 13 in a flow-diagram format. With a general flow from left to right, this diagram illustrates how total GDP (which can be divided into its two primary factor components $P_K K + P_L L$) is separated into the value-added components for the energy ($\mathrm{GDP}_E = P_K K_E + P_L L_E$) and nonenergy ($\mathrm{GDP}_Z = P_K K_Z + P_L L_Z$) sectors*. The energy sector is shown as receiving these primary input factors plus imports $I_E$ plus intermediate inputs $X_E$ plus an allocation for taxes on energy $T_E$ and producing the total value of its output $P_E E$. This energy product is divided between final consumption $E_F$ and intermediate input to the nonenergy sector $E_Z$. The value of the final consumption component is shown in dashed lines rejoining the main stream of flow so that total GDP can be reconstructed and then subdivided into its consumption investment and government purchases components. The nonenergy sector is depicted as receiving primary inputs, energy inputs, and imports $I_Z$ to produce its output $Y_Z$. This output can be expressed as:

$$Y_Z = \mathrm{GDP}_Z + P_E E_Z + I_Z \tag{3}$$

## 3.2 Analysis of Scenario Projections

We define final demand energy as energy consumed in the household sector plus energy used for passenger transportation. In our accounting of energy uses by the MEDEE model, household requirements include space and water heating, lighting and specific uses of electricity. Passenger transportation energy includes all modes of transport. The scenario projection data given in Table A.12 of Appendix A are summarized here in Table 17.

*$P$, $K$, and $L$ represent prices, capital services, and labor services respectively and subscripts $E$ and $Z$ represent the energy sector and nonenergy sector respectively.

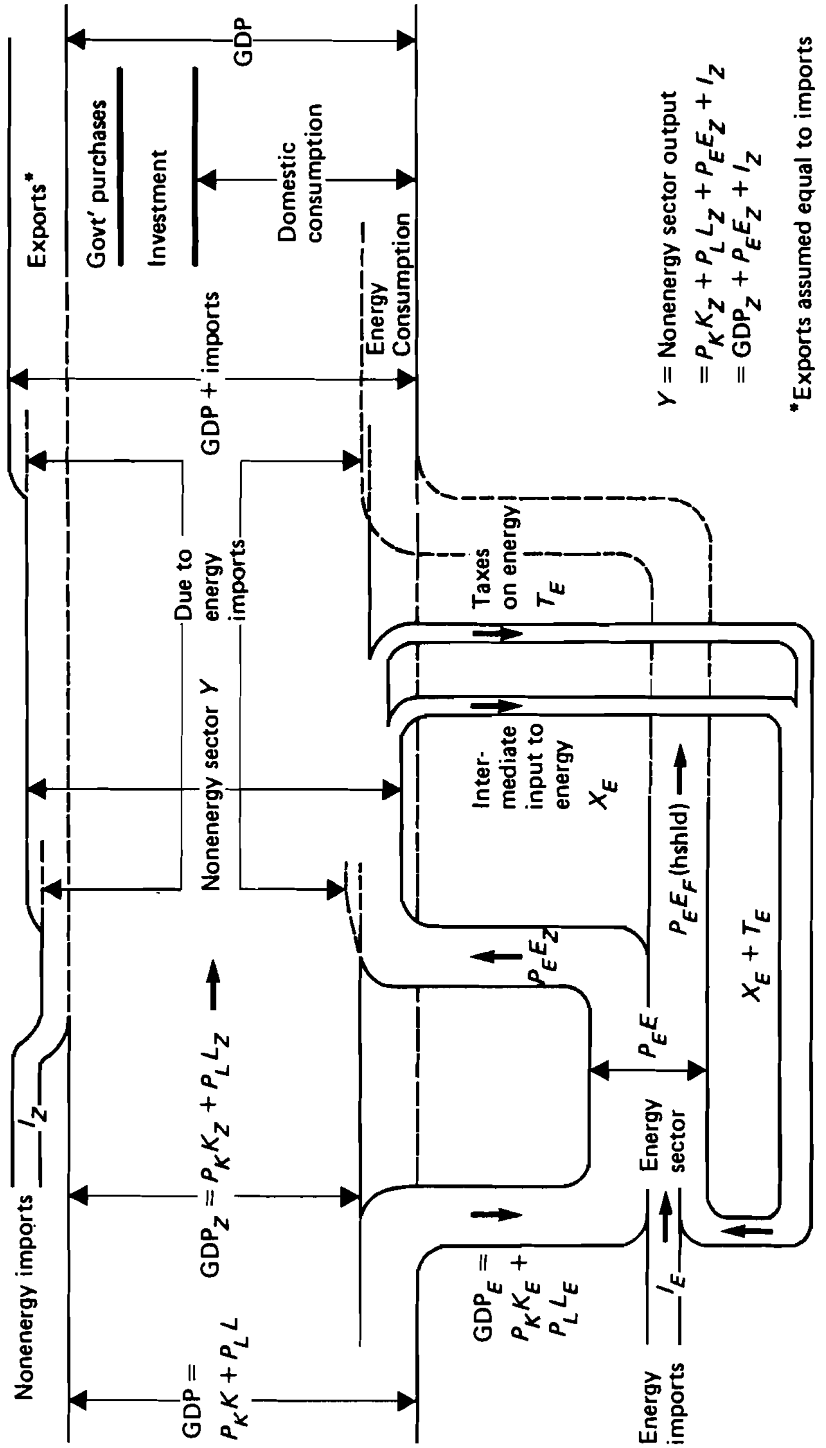



FIGURE 13 Flows in a two-sector economy.

TABLE 17 Final demand energy and intermediate input energy (GWyr/yr).

| Region[c] | Final demand energy[a] 1975 | High 2030 | Low 2030 | Intermediate input energy[b] 1975 | High 2030 | Low 2030 |
|---|---|---|---|---|---|---|
| I (NA) | 809 | 887 | 800 | 1,062 | 2,778 | 1,836 |
| II (SU/EE) | 276 | 662 | 544 | 1,001 | 3,452 | 2,408 |
| III (WE/JANZ) | 591 | 1,410 | 1,080 | 998 | 2,965 | 1,908 |
| IV (LA) | 60 | 619 | 446 | 145 | 2,021 | 1,210 |
| V (Af/SEA) | 57 | 750 | 577 | 196 | 2,423 | 1,299 |
| VI (ME/NAf) | 22 | 329 | 193 | 84 | 1,309 | 675 |

[a] Household commercial energy plus passenger transportation energy (Table A.12).
[b] Total final commercial energy including feedstocks minus final demand energy (Table A.12).
[c] Sectoral analysis is performed only for Regions I through VI for which detailed projections were made.

Energy used as an intermediate input includes feedstocks. Immediately striking is the final demand projection for Region I where energy use drops slightly from 1975 to 2030 in the Low scenario and increases only 10 percent in that period in the High scenario. This is primarily due to the mandated automobile efficiency standards in North America.

We examine the relationship between each of these two categories of energy use and the economy by means of the income and price elasticity ($\gamma$, $\beta$) model of eqn. (2). With that model, we compare energy projections with economic activity projections including the effect of price. For interpretation of final demand energy projections, it is natural to use total GDP as the measure of economic activity. For analyzing intermediate input energy with this model, several points must be raised.

Figures 12 and 13 and eqn. (3) above defined intermediate input energy and the nonenergy sector of the economy. The scenario projections were defined somewhat differently and so these variables cannot be precisely calculated. The energy sector as defined by the MEDEE model includes only the energy conversion industry. Other sector components (mining energy commodities, transmission and distribution of energy) included in the energy sector here are allocated elsewhere in MEDEE. Thus we cannot readily separate either the GDP component or the intermediate input energy requirements of these missing subsectors. For the application of the ($\gamma$, $\beta$) model here, we relate intermediate input energy increases as defined in Table 17 to total GDP increases as defined in Table A.3, Appendix A. That is, rather than make the small adjustments to these data as implied by eqn. (3) (adjustments which compensate each other anyway), we use the GDP and energy data as mentioned above.

To apply the ($\gamma$, $\beta$) model of eqn. (2), we use the same values for the relative price increase that we introduced in Section 2: a factor of 2.4 increase for Region III and 3.0 for all other regions. The values of the income elasticity $\gamma$ and price elasticity $\beta$ which satisfy eqn. (2), for each case, can be represented by straight lines on a graph of $\gamma$ vs $\beta$ as shown earlier in Figures 10 and 11 for the aggregate economy. In all cases, the results show the familiar pattern that the developing regions have values of $\gamma$ greater than those for the developed regions and that the value of unity for $\gamma$ generally serves to separate the developed from the developing regions.

Several observations result from this analysis as described below.

*3.2.1 Comparing High Scenario with Low Scenario*

In all cases, the values for $\gamma$ (for a given $\beta$) are larger for the Low scenario than for the High scenario. This is consistent with the general trend that the income elasticities decrease with increasing economic development: that is, the High scenario has a higher level of economic development and therefore the long-term average values of $\gamma$ should be less for the High than the Low. Another interpretation of this same result is that the High scenario has larger price elasticities ($\beta$s) than the Low scenario: that is, there were stronger conservation effects assumed in the development of the High rather than in the Low scenario.

*3.2.2 Comparing Final Demand Energy with Intermediate Input Energy*

A comparison of the two categories of energy use (household plus passenger transport energy and intermediate input energy) shows that the elasticities for the regions are very different for the final demand category but reasonably close together for the intermediate input category of energy use. Also, in the High scenario, the developed regions have higher $\beta$s and lower $\gamma$s for the final demand category than for the intermediate input category, whereas for the developing regions the two categories are almost identical. In the Low scenario, the effect for the developed regions is less dominant, but for the developing regions the final demand category has lower $\beta$s and higher $\gamma$s than the intermediate input category. These results can be represented as follows:

For final demand energy relative to intermediate input energy:

| Regions | High scenario | Low scenario |
|---|---|---|
| Developed<br>(I, II, and III) | Higher $\beta$s<br>Lower $\gamma$s<br>(very pronounced) | Higher $\beta$s<br>Lower $\gamma$s<br>(less pronounced) |
| Developing<br>(IV, V, and VI) | Same<br>elasticities | Lower $\beta$s<br>Higher $\gamma$s |

For the developed regions, an interpretation of these results is that GDP growth would be accompanied by relatively lower growth (more conservation) in the final demand for energy than in the requirements for intermediate input energy. Conversely, for the developing regions, and especially in the Low scenario, GDP growth would be accompanied by relatively higher growth in the final demand for energy (which is strongly linked to population) than for intermediate input energy.

*3.2.3 Comparing Passenger Transportation Energy with Household Energy*

In this comparison, the High and the Low scenarios exhibit the same result. For Region I only, passenger transportation energy has higher $\beta$s and lower $\gamma$s than household energy. For all other regions the opposite is true. This result indicates the very high efficiency improvements and conservation potential that were realized in these projections for Region I. Equally important is the assumed saturation effect on passenger transportation, which was assumed would apply in this region.

### 3.3 Framework for Five-Sector Economy

In Section 3.1, we defined a two-sector economy with an energy sector and a nonenergy sector. The nonenergy sector can, of course, be disaggregated further. In particular, we examine the industry sector apart from other sectors but for all regions.

For scenario projection purposes, many sectors were accounted for separately in the MEDEE model. These sectors are agriculture, mining, manufacturing (in four subsectors), construction, and services. Transportation (freight and passenger) and household energy uses were separated as well. For our analysis purposes here, we define the industry sector as the mining, manufacturing, and construction sectors of the MEDEE model.

Figure 14 indicates the energy and nonenergy flows in a five-sector model based on MEDEE and defines the industry sector which will be analyzed in detail in Section 5. The industry sector receives imports $I_I$ and intermediate inputs $X_I$ from all other sectors and combines these with its own primary inputs of capital and labor to produce its output.

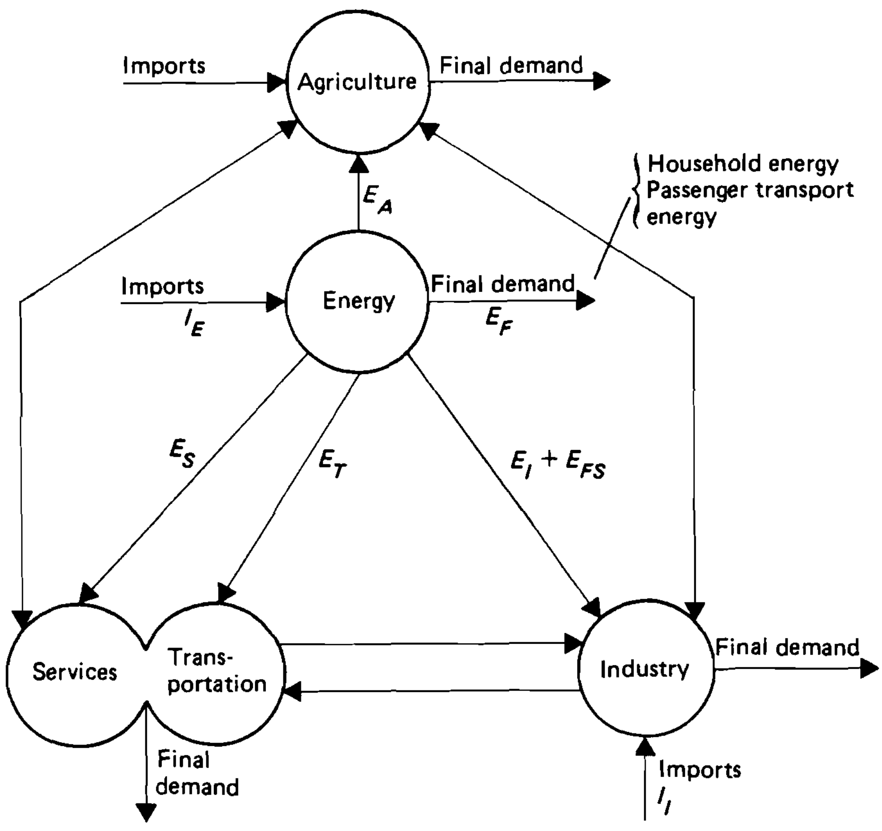



FIGURE 14 Five-sector model of an economy.

The energy inputs are separated into normal energy commodities $E_I$ and commodities that are used as feedstocks $E_{FS}$. Its total output $Y_I$ can be expressed as:

$$Y_I = \mathrm{GDP}_I + P_E E_I + P_E E_{FS} + I_I + X_I \tag{4}$$

In our analysis of this sector, we will make the simplifying assumption that imports plus intermediate inputs maintains a constant share of output so that we need only consider the primary input factors $\mathrm{GDP}_I$ and the energy term. Since we will be examining the substitution effect of nonenergy inputs for energy inputs we will consider only those energy inputs that are used as energy $E_I$ and consider the feedstock component as another intermediate input included with $X_I$.

## 4 ENERGY–NONENERGY SUBSTITUTION AND TECHNOLOGICAL DEVELOPMENT: A MODEL

The objective of this analysis is to examine the substitution between energy and other factors of production and how this substitution affects both the price of energy and the structure of the economy in general. In Section 3, the accounting structure was described within which we identify and measure energy as an intermediate input and how the energy sector interacts with the other sectors of the economy. The vehicle for analyzing factors of production and substitution is the production function. In this section, we specify the family of production functions that we use, we define the elasticity of substitution of factors of production and give some examples to assist in the interpretation of these concepts in our application. This approach follows that of Manne 1977.

As described earlier, the factors of production that we consider are capital, labor, and energy. In the explication of the basic concepts immediately following, we examine the case with only two unspecified factors of production. We will later identify one factor $x$ as energy and the other $z$ as a combination of the primary inputs capital and labor. The $z$ factor can eventually be split into its two basic components.

In an ideal production system, a production function defines the amount of output or product that can be produced from the specified quantities of inputs. In conceptual form, all quantities are measured in real, physical units. If we denote the output product in some units by $y$ and the two input factors in their units by $x$ and $z$, then the production function $f$ defines the maximum feasible output for any combination of inputs, that is:

$$y = f(x,z) \tag{5}$$

We will be interested mainly in the combinations of $x$ and $z$ that yield a given $y$ or simply the substitution of $x$ for $z$ (or vice versa) from some given mix that will maintain the same quantity of output $y$.

### 4.1 Static Economy

The first question that arises with respect to substitution is how much of one factor is required to substitute for another factor. In Figure 15, the combinations of factors $x$ and

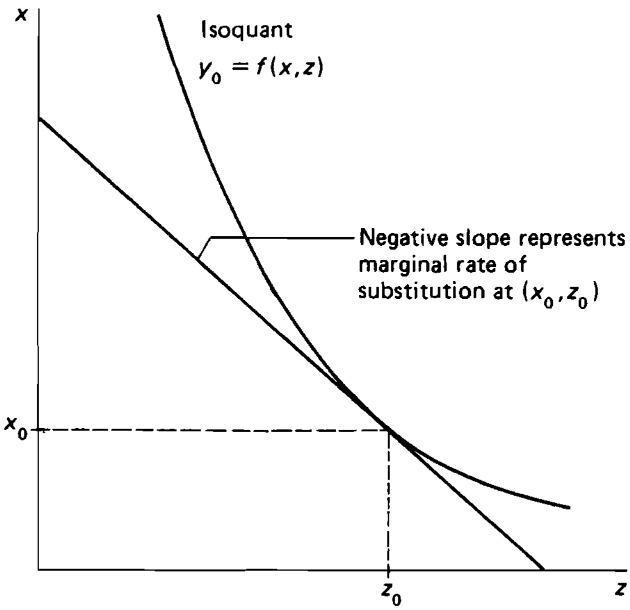



FIGURE 15 Isoquant and marginal rate of substitution.

z that could be used to produce a given output are illustrated by a curved line called an *isoquant*. At any point on this isoquant, there is a tradeoff between using more of one factor and less of the other. We formally define this tradeoff as the *marginal rate of substitution* of $x$ and $z$, which is denoted $R(x,z)$ and defined as:

$$R(x,z) = -\frac{\mathrm{d}x}{\mathrm{d}z} = \frac{f_z}{f_x} \tag{6}$$

where $f_x$ and $f_z$ denote the partial derivatives of the production function $f$ with respect to $x$ and $z$. The marginal rate of substitution is illustrated in Figure 15 as the slope of the isoquant. It is reasonable to assume that $R$ increases as more and more $x$ is substituted for $z$ as illustrated in the figure. This implies that the isoquants of constant output are convex to the origin. It is clear that, except for the case of a production function of the form $f = ax + bz$ in which the isoquants are straight lines, the marginal rate of substitution depends on the mix of inputs.

Another concept that measures the substitutability of input factors is the *elasticity of substitution*. (See for example Allen 1967.) Denoted by $\sigma$, it is defined by:

$$\sigma = \frac{\mathrm{d}\log(x/z)}{\mathrm{d}\log R(x/z)} \tag{7}$$

with output $y$ held constant. In a different form, it can be expressed as

$$\sigma = \frac{z}{x} R \frac{\mathrm{d}(x/z)}{\mathrm{d}R} = \frac{\dfrac{\mathrm{d}(x/z)}{x/z}}{\dfrac{\mathrm{d}R}{R}} \tag{8}$$

which is explained below.

As with all elasticities, this concept is a ratio of two relative changes. What is initially confusing, perhaps, is that the numerator is a relative change ($\mathrm{d}u/u$) of a variable that is itself defined in relative terms ($u = x/z$). Expressed in words, the elasticity of substitution is the ratio of the relative change in the (relative) mix of inputs to the relative change in the marginal rate of substitution of these inputs. Thus for an elasticity of unity, a 1 percent change in the relative amounts of $x$ and $z$ is accompanied by a 1 percent change in the marginal rate of substitution. That is, for constant output, a small shift toward using more $x$ is accompanied by a similar small increase in the marginal rate of substitution so that any *further* shifts toward more $x$ will require relatively more $x$. For an elasticity of 0.25, for example, a 1 percent change in relative amounts of $x$ and $z$ will be accompanied with a 4 percent change in the marginal rate of substitution. Figure 16 shows several isoquants that exhibit constant but different elasticities of substitution.

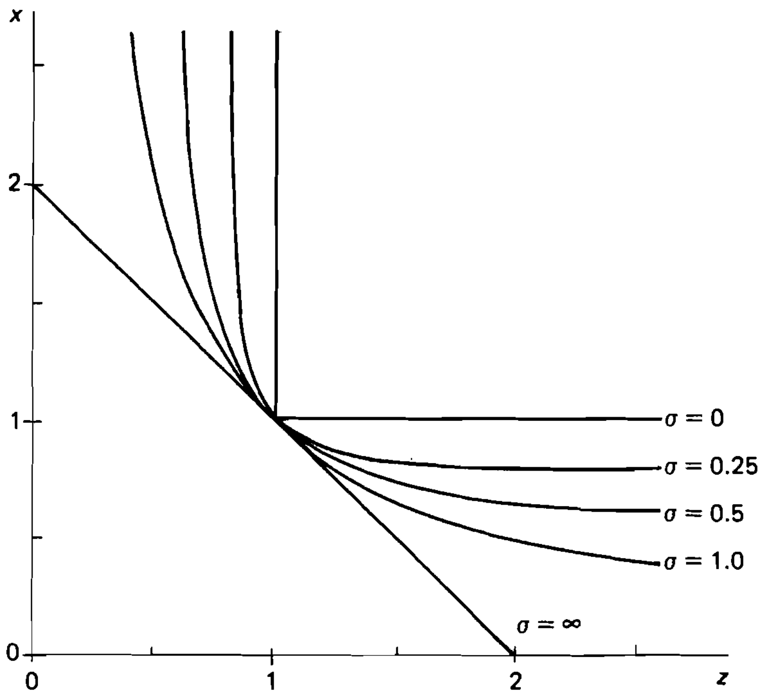



FIGURE 16 Isoquants for different values of elasticity of substitution.

We now introduce two specific forms for the production function; one is the Cobb-Douglas and the other is the constant elasticity of substitution (CES) form. The Cobb-Douglas production function has the form:

$$y = x^{\alpha} z^{\beta} \tag{9}$$

where $\alpha$ and $\beta$ are greater than zero. For constant returns to scale, $\alpha + \beta$ must be unity and then $\beta = 1 - \alpha$. In this case, it is straightforward to show that the elasticity of substitution is unity and it can also be shown that the Cobb-Douglas production function with constant returns to scale is the *only* production function with $\sigma = 1$.

The second specific form of production function to be used in this analysis is the CES production function, which takes the form:

$$y = \left(ax^{\rho} + bz^{\rho}\right)^{\frac{1}{\rho}} \tag{10}$$

where $a$ and $b$ are positive constants and $\rho$ is a parameter not equal to zero. The elasticity of substitution of this production function is:

$$\sigma = \frac{1}{1-\rho} \tag{11}$$

It can also be shown that eqn. 10 is the *only* form of production function with constant returns to scale that has a constant elasticity of substitution. The isoquants of Figure 16 are derived from this production function (except for the limiting case of $\rho = 0$ and $\sigma = 1$ for which this form is consistent with the Cobb-Douglas form).

In order to gain the full potential of production function analysis, we assume that production is based on profit maximization under perfect competition. Under these conditions, producers take prices as given and production is determined by equating the marginal productivity of each factor of production to its price. In mathematical form, this implies that the prices for $x$ and $z$ are given by:

$$p_x = f_x \quad \text{and} \quad p_z = f_z \tag{12}$$

For the CES production function of eqn. (10) these equilibrium prices are:

$$p_x = ax^{\rho-1}(ax^{\rho} + bz^{\rho})^{(1-\rho)/\rho} = a\left(\frac{y}{x}\right)^{1-\rho} \tag{13}$$

$$p_z = bz^{\rho-1}(ax^{\rho} + bz^{\rho})^{(1-\rho)/\rho} = b\left(\frac{y}{z}\right)^{1-\rho} \tag{14}$$

These prices are measured in the physical units of the product $y$ or, equivalently, in an appropriate numéraire (say monetary) with the product price defined as unity.

The conditions already assumed for the definition of the CES production function and the prices above are sufficient to ensure that the value of the product can be exactly divided into the value contributed by the factors of production, that is:

$$y = p_x x + p_z z \tag{15}$$

which can be verified by substituting the expressions for $p_x$ and $p_z$ from eqns. (13) and (14).

Using the assumption regarding prices of eqn. (12), the definition of the elasticity of substitution $\sigma$ can be restated in relative price terms. Since the marginal rate of substitution $R$ is simply the ratio of the prices of $x$ and $z$, eqn. (8) can be stated as follows

$$\sigma = \left[\frac{\mathrm{d}(x/z)}{x/z}\right] \Bigg/ \left[\frac{\mathrm{d}(p_z/p_x}{p_z/p_x}\right] \tag{16}$$

Thus the elasticity of substitution is the ratio of the relative change of the relative mix of $x$ and $z$ to the relative change of the relative prices of $z$ and $x$. The relative amount of $x$ decreases if the relative price of $x$ increases.

The relationship between the elasticity of substitution and the more common price elasticity can be investigated by means of eqns. (13) or (14). Considering the use of the factor of production $x$, eqn. (12) can be rewritten as:

$$x = a^{1/(1-\rho)} y \, p_x^{-1/(1-\rho)} \tag{17}$$

which is:

$$x = a^{\sigma} y \, p_x^{-\sigma} \tag{18}$$

where $\sigma$ is the elasticity of substitution as given by eqn. (11).

The normal definition of a price elasticity relates the change in use of a commodity to the change in its price after all other changes have occurred in the economy. Thus, this definition compares two equilibrium states of the economy, before and after the price change. The price elasticity $\tau$ of $x$ is defined by:

$$\tau = \frac{p_x}{x} \frac{\mathrm{d}x}{\mathrm{d}p_x} \tag{19}$$

From eqn. (18), this becomes:

$$\tau = -\sigma + \frac{p_x}{y} \frac{\mathrm{d}y}{\mathrm{d}p_x} \tag{20}$$

That is, the price elasticity is the elasticity of substitution (with opposite sign) plus the elasticity of change of output $y$ to a change in price of $x$. Without a further assumption, the second term of eqn. (20) cannot be evaluated. One must be careful in making this evaluation to guarantee that the price elasticity of eqn. (19) makes sense. Only the changes of output $y$ *due to the change in price of* $x$ should be counted. If the states of an economy are compared at different times during which there happened to be a price change, there may have been other factors affecting output $y$. A growing economy is an obvious example. Between two points in time, the price of $x$ may increase but output and the use of $x$ may also increase due to overall growth. This is not the change in $y$ meant in eqn. (20).

If the output is relatively independent of the price of $x$, then the price elasticity is numerically equal to the elasticity of substitution. That is, for *constant output* we have:

$$\tau = -\sigma \tag{21}$$

A better approximation to the full price effect can be achieved by assuming that the quantity of factor $z$ is held constant and the output is allowed to change. In this case, we have:

$$\frac{dy}{dp_x} = \frac{dy}{dx}\,\frac{dx}{dp_x} = p_x\,\frac{x\tau}{p_x} = x\tau \qquad (22)$$

with $z$ *held constant*. Then by substituting into eqn. (20), we get:

$$\tau = -\sigma/[1-(p_x x)/y] = \frac{-\sigma}{1-s} \qquad (23)$$

where $s$ is the relative value share of $x$ in output $y$. In the case of energy, its value share is relatively small so that $\tau$ and $\sigma$ are approximately equal in magnitude.

## 4.2 Technological Development

To this point in our development, we have been dealing with a static economy. We will eventually apply these concepts in a dynamic situation. In the developed economies, historical data analysis usually indicates that capital–output ratios, labor–output ratios and energy–output ratios decline over time as output is increasing. The production functions introduced above cannot explain these changes so that further assumptions or modifications must be made.

One such modification is the introduction of the concept of technological development. In its simplest form, this concept allows for more product to be produced from the same physical inputs as time progresses. In mathematical form, it can be defined as an exponentially increasing multiplicative factor so that output $y$ is given as follows:

$$y = e^{\delta t} f(x,z) \qquad (24)$$

where $t$ represents time (in years) and $\delta$ is (approximately) the annual percentage increase in output per unit of input.

Treating technological development in this way implies that all (or both) inputs enjoy the same rate of technological development or improvement with time. This is, of course, a simplification. It is not intended, however, that this multiplicative factor should represent *all* the effects which contribute to the decreasing output–input ratios. Output per physical unit of labor (labor productivity) is not entirely due to technological development nor is the factor $e^{\delta t}$ intended to represent all of labor productivity – similarly for capital and energy inputs. We separate technological development as a factor of overall improvement in product per unit input because it is an important factor which has provided more for less in the past and we assume that it will continue to some extent for the future. The factor $e^{\delta t}$, therefore, is the average technological development factor which is assumed to apply to all inputs and other "more for less" factors are represented otherwise. In particular, labor productivity increases over and above those due to technological development are assumed to be included in the definition of the measurement of the labor input. Thus, labor input is not measured in man-hours or like units but in "labor-equivalent" units relative to a base year that represents the differential productivity increases. The price of these inputs is defined accordingly to account for their "observed" value in the production function formulation. For example, if labor productivity increases apart from those due to technological development could be represented by a percentage increase, $k$ per year, then the labor input could be defined as $e^{kt}L$ where $L$ is measured in physical units.

Taking account of the $e^{\delta t}$ factor of eqn. (24), our expressions for the prices of $x$ and $z$ change slightly. Using the CES form of the production function, these prices are now:

$$p_x = e^{\delta t} f_x = e^{\delta t} a \left(\frac{f}{x}\right)^{1-\rho} = a\, e^{\rho \delta t} \left(\frac{y}{x}\right)^{1-\rho} \qquad (25)$$

and

$$p_z = e^{\delta t} f_z = e^{\delta t} b \left(\frac{f}{z}\right)^{1-\rho} = b\, e^{\rho \delta t} \left(\frac{y}{z}\right)^{1-\rho} \qquad (26)$$

It is easy to see that with $\delta = 0$, these reduce to eqns. (13) and (14). The comparable expression to eqn. (18) for $x$ as a function of $p_x$ is

$$x = a^{\sigma} e^{-(1-\sigma)\delta t} y\, p_x^{-\sigma} \qquad (27)$$

where $\sigma$ is the elasticity of substitution as given by eqn. (11).

### 4.3 Dynamic Economy

We gain some insight into the implication of the production function formulation and the equilibrium price assumptions if we examine these equations as defining a system that evolves in time. This system is determined by eqns. (24), (25), and (16) in the five variables $x$, $y$, $z$, $p_x$, and $p_z$. Once the production function $f$ and technological development parameter $\delta$ are given then the evolution of the system from some initial point is determined once two of the five variables are specified. We will be interested in the dynamics of this system for various assumptions about the changes in price of $x$ (which will represent energy in our later application) but initially we gain better understanding of this system by examining some simple cases.

If inputs $x$ and $z$ are both held constant over time at values $x_0$ and $z_0$, then output $y$ is given by:

$$y = e^{\delta t} f(x_0, z_0) = e^{\delta t} f_0 \qquad (28)$$

which increases at the rate $\delta$ of technological development. The equilibrium prices of $x$ and $z$ are given by eqns. (25) and (26) as:

$$p_x = e^{\delta t} f_x(x_0, z_0) = p_{x0} e^{\delta t} \qquad (29)$$

and

$$p_z = e^{\delta t} f_z(x_0, z_0) = p_{z0} e^{\delta t} \tag{30}$$

These prices increase at the same rate as technological development which is consistent with the assumption of prices being equal to marginal productivity. Notice that the output $y$ still divides exactly into the value share for $x$ and $z$ since the initial condition must satisfy:

$$p_{x0} x_0 + p_{z0} z_0 = f_0 \tag{31}$$

As a second case, assume that output $y$ increases with growth rate $g$ and that there is no relative price change between $x$ and $z$. Then:

$$y = y_0 e^{gt} \tag{32}$$

$$x = x_0 e^{(g - \delta)t} \tag{33}$$

and

$$z = z_0 e^{(g - \delta)t} \tag{34}$$

so that the growth in output is maintained by growth in inputs $x$ and $z$ at a rate of $g - \delta$ to account for the technological development.

In an earlier section, we defined an elasticity $\epsilon$ as the ratio of the relative change in energy to the relative change in gross output or GDP. If input $x$ is interpreted as an energy input, then this elasticity becomes:

$$\epsilon = \frac{dx/x}{dy/y} \tag{35}$$

In this simple growth case, $dx/x$ is $g - \delta$ and $dy/y$ is $g$ so that:

$$\epsilon = \frac{g - \delta}{g} = 1 - \frac{\delta}{g} \tag{36}$$

For small economic growth with $g = \delta$ then this elasticity is zero, that is, with economic growth due to technological development only there is no increase in inputs (zero energy growth).With $g \gg \delta$ then this elasticity is close to but smaller than unity. For $g = 5\delta$, $\epsilon = 0.8$.

Notice that with this model of an economy which results in the definition of eqn. (36) for the energy–GDP elasticity, this elasticity is always less than unity (assuming that $\delta$ and $g$ are both positive). Thus it cannot explain the development of a developing economy in the aggregate since we have already seen that this elasticity is usually greater than unity in these cases. The implication is that a single production function cannot properly explain the aggregate economy *over time* because the developing economy is changing rapidly in texture such that it *does* require more energy for the "same" aggregate output as the economy shifts from agriculture to energy-intensive industry. This model may be useful, however, for certain reasonably homogenous sectors of a developing economy and, in fact, we will apply it to the industry sector of six regions in Section 5.

To examine the effects of changing prices, it is useful to use the specific CES production functions. In this case, we can express the quantity of inputs required as a function of price as shown, for example, in eqn. (27). By rearranging eqn. (27) we have:

$$x = \frac{y}{e^{\delta t}} \left( \frac{p_x}{ae^{\delta t}} \right)^{-\sigma} \tag{37}$$

which shows very clearly that if output $y$ and price $p_x$ increase at the rate $\delta$ then the equilibrium quantity of $x$ remains constant. It is useful to define all the variables of this system in terms of their initial or base year values. Thus the measurement of the quantitites of $x$, $y$, and $z$ become relative to, or multiples of, base year values and the initial conditions of the system can be set at unity. With $t = 0$ and $x$, $y$, and $z$ at unity, the initial prices for $x$ and $z$ are $a$ and $b$, respectively, as can be seen from eqns. (25) and (26) provided that the price of $y$ is defined to be unity. Then $p_x/a$ becomes the price of $x$ relative to its base year value and we denote this price as $p_x^r$. We similarly define $p_z^r$. Equation (37) can be simplified to:

$$x = \frac{y}{e^{\delta t}} \left( \frac{p_x^r}{e^{\delta t}} \right)^{-\sigma} \tag{38}$$

which allows us to make a very important observation: there is no effect on the use of input factor $x$ *due to substitution* as long as its price relative to the base year value *increases at the rate of technological development*. If the price of $x$ is held constant (in real terms), the effect is to increase substitution to use *more* $x$ because it is undervalued vis-à-vis other inputs and marginal productivity. A constant price in real terms is therefore a decreasing price relative to other inputs but is still constant relative to the price of the output $y$.

To continue with our examination of the dynamics of this system, we require an expression of the time rate of change of $x$. By differentiating eqn. (38) with respect to $t$ we obtain:

$$\frac{\dot{x}}{x} = \frac{\dot{y}}{y} - (1 - \sigma)\,\delta - \sigma \frac{\dot{p}_x^r}{p_x^r} \tag{39}$$

If we now let $g$ and $\pi$ (both possibly time varying) represent the growth rates $\dot{y}/y$ and $\dot{p}_x^r/p_x^r$, respectively, then:

$$\frac{\dot{x}}{x} = g - \delta - \sigma(\pi - \delta) \tag{40}$$

That is, the growth rate of $x$ is equal to the growth rate of $y$ minus technological development and minus the elasticity of substitution times the growth rate of the price of $x$ in excess of the "normal" price increase due to technological development.

Whenever the price of $x$ is different from that due to technological development ($\pi \neq \delta$) then there is substitution between $x$ and $z$. This substitution causes a change in the marginal productivity of $z$ and so its price will change. By using the basic relation:

$$y = p_x x + p_z z \tag{41}$$

and the already derived dynamics of $x$ and $p_x$ we can show that:

$$\frac{\dot{p}_z}{p_z} = \delta - (\pi - \delta)\frac{s}{1-s} \tag{42}$$

where $s$ is the value share of $x$ in $y$, that is:

$$s = \frac{p_x x}{y} = a^{\sigma} e^{-(1-\sigma)\delta t} p_x^{1-\sigma} \tag{43}$$

If $x$ is interpreted as the energy input then its value share is a small part of total GDP. Even if this value share changes by a factor of two in the future due to real price increases, the fraction $s/(1-s)$ is still small and so eqn. (42) shows that the price of $z$ is affected only slightly even if $\pi$ is substantially larger than $\delta$. The expression for the growth rate of $z$ itself comparable to eqn. (40) is:

$$\frac{\dot{z}}{z} = g - \delta + \sigma(\pi - \delta)\frac{s}{1-s} \tag{44}$$

which shows, as expected, that if $\pi > \delta$ then $z$ grows faster than would normally be required $(g - \delta)$ but that the required increase is small because of the value share fraction $s/(1-s)$.

A development similar to that above which resulted in eqns. (42) and (44) results in expressions for $p_z$ and $z$ as a function of $p_x$. These are presented here and will be useful later:

$$p_z^r = e^{\delta t}\left[\frac{1 - a(e^{-\delta t}p_x^r)^{1-\sigma}}{1-a}\right]^{1/(1-\sigma)} \tag{45}$$

$$z = \frac{y}{e^{\delta t}}\left[\frac{1-a}{1 - a(e^{-\delta t}p_x^r)^{1-\sigma}}\right]^{\sigma/(1-\sigma)} \tag{46}$$

We see immediately that if $p_x^r$ increases only at the rate of technological development $(e^{\delta t})$ then $p_z^r$ increases also at this rate and $z$ increases only to the extent that output $y$ increases above technological development. The expression in the square brackets of eqn. (46) to the power $\sigma/(1 - \sigma)$ defines the relative amount of other input ($z$) required over and above its normal value $(y/e^{\delta t})$, the increase which is due to substitution when $p_x^r$ is higher than $e^{\delta t}$.

In summary, if we treat eqns. (24), (25), and (26) as defining a dynamic system, we can choose any two variables from $x$, $y$, $z$, $p_x$, $p_z$ as independent and the remaining are determined by the system. In particular, if we choose $y$ and $p_x$ by specifying their growth rates over time ($g$ and $\pi$) then $x$ is given by eqn. (40), $p_z$ by eqn. (42) and $z$ by eqn. (44) where $s$ is already defined by eqn. (43) in terms of $p_x$.

Finally, we can express the changing role of $x$ in the economy by the ratio of its growth rate to that of $y$. This elasticity $\epsilon$ is given by

$$\epsilon = \frac{\dot{x}/x}{g} = 1 - \frac{\delta}{g} - \sigma\frac{\pi - \delta}{g} \tag{47}$$

Typical parameter values are $g = 5$ percent per year, $\delta = 0.5$ percent per year and $\sigma = 0.25$. If then the price of $x$ increases by 2.5 percent per year over some period, we have

$$\epsilon = 1 - 0.1 - 0.1 = 0.8 \tag{48}$$

for that period. Thus we see that the substitution effect can be approximately equal in importance to the technological development effect in reducing the demand for energy. We examine the scenario projection data with these models in Section 5.

## 5 ENERGY–NONENERGY SUBSTITUTION AND TECHNOLOGICAL DEVELOPMENT: ANALYSIS OF SCENARIO PROJECTIONS

The model just described can be usefully applied in two ways in analyzing the scenario projections. For the industry sector itself, it can be applied to all regions, whether developed or developing, because within this sector, the possibilities for substitution from energy inputs to nonenergy inputs and for technological development are more easily understood. Another application for this model is the nonenergy sector in total as defined in Section 3 but this application must be restricted to the developed regions. As noted in the description of the model, the effects of both substitution (with increasing energy prices) and technological development contribute to using less energy per unit output. We have already seen that developing regions are projected to require more energy per unit of aggregate output ($\epsilon$s and $\gamma$s are greater than unity) not because of inefficiencies but because of a shift in the sectoral composition of the developing economy. For the developed regions, on the other hand, the sectoral shifts are less pronounced and the application of the ($\delta$, $\sigma$) model of technological development and substitution will have a meaningful interpretation. We examine the intermediate input energy consumption by the nonenergy sector of the economy for Regions I, II, and III first and then examine the industry sector (mining, manufacturing, and construction) for Regions I through VI later.

In the application of the ($\delta$, $\sigma$) model described in Section 4, we use scenario data to define GDP or output, energy consumption, and the relative price increase of energy. Then we calculate the values of the parameters $\delta$ and $\sigma$ which are consistent with these data. This calculation is based on eqn. (38) which, when interpreted with input $x$ as energy $E$ (relative to its base year value), is written as follows:

$$E = e^{-(1-\sigma)\delta t} y (P_E^r)^{-\sigma} \tag{49}$$

By rearrangement, this equation gives an expression for $\sigma$ in terms of $\delta$ as:

$$\sigma = \frac{\delta T + \log (E/y)}{\delta T - \log (P_E^r)} \tag{50}$$

where $T$ specifies the particular time period of 55 years (from 1975 to 2030) in our applications.

After we examine the range of values of $\sigma$ and $\delta$ which satisfy eqn. (50) for each region and scenario we arbitrarily choose a specific combination for each application for illustrative purposes in order to examine further implications of the ($\delta$, $\sigma$) model. These other implications involve the degree of substitution of nonenergy inputs for energy inputs, the price changes for the nonenergy inputs due to substitution, and the relative contribution in the scenario projections.

The effect on the price of the nonenergy inputs $Z$ due to substitution is given by eqn. (45). This drop in price relative to what the price would have been without substitution is given by:

$$(P_Z^r)\dagger = \mathrm{e}^{-\delta T} P_Z^r = \left[ \frac{1 - a(\mathrm{e}^{-\delta T} P_E^r)^{1-\sigma}}{1-a} \right]^{1/(1-\sigma)} \tag{51}$$

where $(P_Z^r)\dagger$ is the price of $Z$ with substitution relative to its price without substitution and $a$ is the relative value of energy in the total output y at the beginning of the time period. The term $\mathrm{e}^{-\delta T}$ adjusts the relative price $P_Z^r$ for the "natural" price increases of the nonenergy inputs due to technological development (see Section 4). Once the relative price of the nonenergy inputs is known, the relative change in price between energy and nonenergy inputs can be calculated.

Finally, the increase in use of nonenergy inputs due to substitution is given by eqn. (46).

$$(Z^r)\dagger = \left[ \frac{1-a}{1 - a(\mathrm{e}^{-\sigma T} P_E^r)^{1-\sigma}} \right]^{\sigma/(1-\sigma)} = (P_Z^r)\dagger^{-\sigma} \tag{52}$$

where $(Z^r)\dagger$ is the quantity of inputs $Z$ required with substitution relative to that without substitution.

### 5.1 The Aggregate Nonenergy Sector

Our definition of the nonenergy sector was given in Section 3.1 and is illustrated in Figure 12. In this application of the ($\delta$, $\sigma$) model, we analyze the same data as were analyzed in Section 3 with the ($\gamma, \beta$) model. The data for the relative increase in GDP are taken from Table A. 3 in Appendix A. The energy input to this sector, as depicted in Figure 12, is intermediate input energy and is given in Table 17. The relative price increase for energy is as used throughout this report (2.4 times for Region III and 3.0 times otherwise).

The values of $\delta$ and $\sigma$ as defined by eqn. (50) are shown graphically in Figure 17 for Regions I, II, and III for both the High and Low scenarios. This figure shows that relatively greater improvements in terms of output per unit of energy are projected for Region II in both the High and Low scenarios than for Regions I and III since combinations of $\delta$ and $\sigma$ are larger for Region II. That is, Region II has a higher rate of technological development ($\delta$) or a higher elasticity of substitution ($\sigma$) (or both) such that by 2030 equivalent output is being produced with less energy input. Similarly, for Regions I and III, the High scenario projections represent greater technological development and/or substitution than the corresponding Low scenario. This figure also shows that if technological development is not included in the model (the case of $\delta = 0$) the elasticities of substitution implied by the projections are very large – between 0.34 and almost 0.8 for the three regions.

In order to determine the implied price decrease of the nonenergy inputs and the relative increase in use of these inputs due to substitution [eqns. (51) and (52)], we choose specific values of $\delta$ and $\sigma$ from Figure 17. For this purpose, we arbitrarily choose those values as defined by the dashed line in the figure. These values, given in Table 18, range between 0.24 percent per year and 0.68 percent per year for technological development

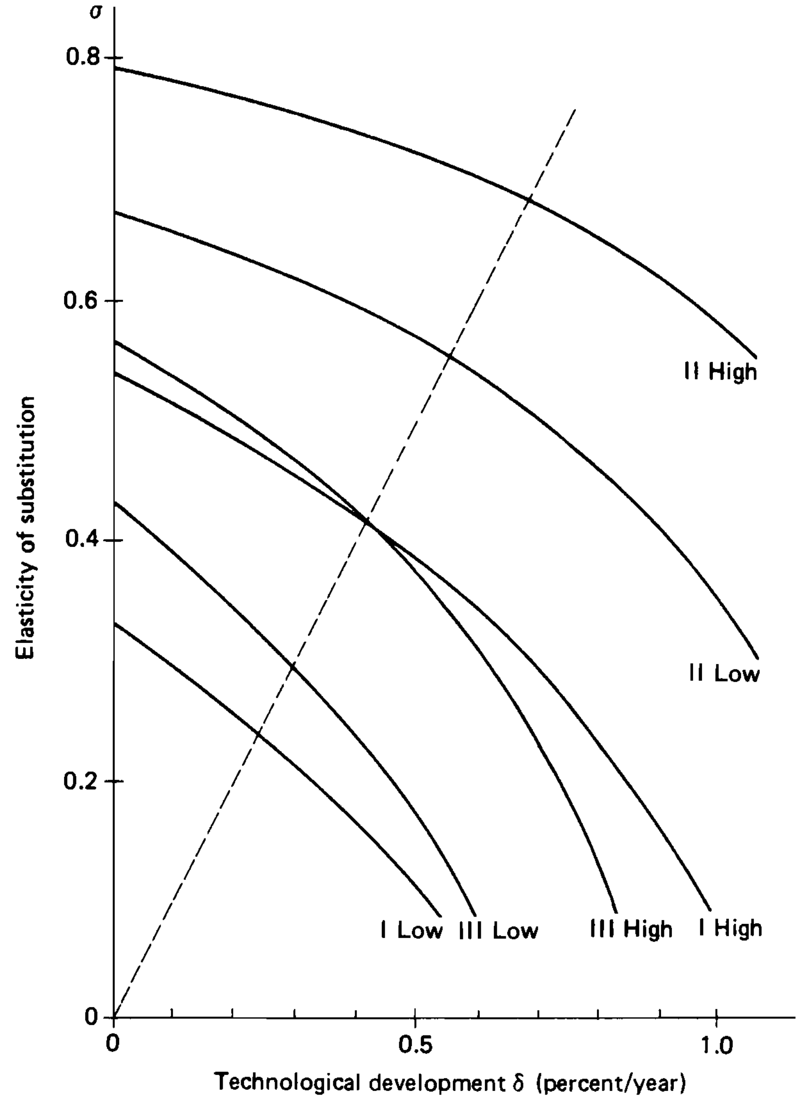



FIGURE 17 Technological development and substitution in the nonenergy sector in developed regions.

which seem reasonable given our definition of this concept.* The corresponding elasticities of substitution also range from 0.24 to 0.68 as a consequence of our selection of points. These may appear low compared to what other analyses have indicated but are lower because of the inclusion of the technological development factor.

*These should not be interpreted as labor productivity increases since in our definition, technological development is only one component of productivity increases.

TABLE 18 Application of the (δ, σ) model to the nonenergy sector.

| Region | Technological development[a] δ (percent/ year) | Elasticity of substitution[a] σ | Value share of energy[b] *a* (percent) | Energy/ nonenergy relative price[c] | Increase in nonenergy inputs[d] (percent) |
|---|---|---|---|---|---|
| *High scenario* | | | | | |
| I (NA) | 0.42 | 0.42 | 3.2 | 2.5 | 1.6 |
| II (SU/EE) | 0.68 | 0.68 | 7.7 | 2.2 | 4.8 |
| III (WE/JANZ) | 0.42 | 0.42 | 3.2 | 2.0 | 1.1 |
| *Low scenario* | | | | | |
| I (NA) | 0.24 | 0.24 | 3.2 | 2.8 | 1.2 |
| II (SU/EE) | 0.55 | 0.55 | 7.7 | 2.4 | 4.6 |
| III (WE/JANZ) | 0.30 | 0.30 | 3.2 | 2.1 | 0.9 |

[a] Representative values of technological development δ (percent/year) and elasticity of substitution σ as shown in Figure 17.

[b] Ratio of intermediate input energy payments [calculated with 1975 energy use data and base year (1972) final energy prices (Table 13)].

[c] See page 53.

[d] Shows percentage increase of nonenergy inputs required with substitution due to energy price increase relative to inputs required without substitution.

For these specific values of technological development (δ) and substitution (σ), it is possible to calculate the relative contribution of these two factors to overall energy conservation. This can be done by using eqn. (47) which expresses the energy–GDP elasticity $\epsilon$ in terms of δ, σ, and growth rates of output and prices. From that equation, the relative importance of δ and σ in reducing $\epsilon$ from unity can be easily derived. Following this procedure, we see that technological development contributes from 36 percent to 46 percent to energy conservation (and substitution, the remaining 64 percent to 54 percent) according to this model.

To examine the implications of the (δ, σ) model further, we require estimates of the value share, in the base year, of energy as an input to the nonenergy sector (parameter $a$ in eqns. (51) and (52)). For this parameter, we estimate the total payments for the intermediate input energy and compare them with total GDP. Final (delivered) energy prices were discussed in Section 2 and summarized in Table 13. These prices include all factors, including taxes, that make up the delivered energy price. Using the given prices for Regions I and III and the Region I prices for Region II, we calculate energy payments using final energy consumption data from Table A.12 for freight transportation, for the service and industry sectors and including feedstocks. The resulting value share parameters, as shown in Table 18, range from 3 percent to almost 8 percent.

The data for δ, σ, and $a$ in the first three columns of Table 18 can be used to calculate the extent of the substitution of nonenergy inputs for energy inputs. Equation (51) gives the relative *decrease* in nonenergy input prices. This decrease is relative to what prices would be if there were no energy price increase to cause the substitution. Based on the data given, this decrease would range from 0.92 to 0.97 depending on the region. The combination of the energy price increase and this nonenergy price decrease gives a relative price differential between these two inputs of between 2.0 and 2.8. It is important to understand the reason why this input relative price is less than the overall relative increase in energy price (either 3.0 or 2.4 depending on region). The $(\delta, \sigma)$ model allocates part of the energy price increase to increases in productivity due to technological development (at the rate of $e^{\delta t}$). As indicated in Section 4 where the model was described, the energy price increase which causes substitution between energy and nonenergy inputs must be increases over and above the "normal" price increases due to efficiency improvements of technological development. It is the energy price increases in excess of that due to technological development which when combined with the price decrease of nonenergy input that defines the relative price change of these two inputs.

Finally, as given in Table 18, eqn. (52) implies that the nonenergy inputs must be increased because of substitution by 1–1½ percent in Regions I and III and almost 5 percent in Region II. The much larger value for Region II is due to the estimated large value share (7.7 percent) of energy in the economy in the base year. These are increases over and above what would be required to produce the increased output to make up for the substitution away from energy inputs.

Having applied both the $(\delta, \sigma)$ and $(\gamma, \beta)$ models to the nonenergy sector allows us to make a comparison of these two models. According to the $(\delta, \sigma)$ model, energy requirements are defined by eqn. (49) whereas for the $(\gamma, \beta)$ model eqn. (2) applies. Rewriting this latter equation in the notation of this section gives:

$$E = y^{\gamma}(P_E^r)^{\beta} \tag{53}$$

A comparison with eqn. (49) indicates that for equivalence we must have:

$$\beta = -\sigma \tag{54}$$

and

$$y^{\gamma} = e^{-(1-\sigma)\delta t} y \tag{55}$$

The equivalence of $\beta$ and $\sigma$ is quite natural given the interpretation of $\sigma$ as an approximation to a price elasticity as shown in Section 4, eqn. (20). The equivalence implied by eqn. (55) shows that the decreasing energy–output ratio, observed in historical data analysis and projected to continue even stronger in the future, is accounted for very differently in the two models. In the $(\gamma, \beta)$ model, this characteristic is some sort of economy of scale (larger $y$ implies less energy per unit $y$). In the $(\delta, \sigma)$ model this decreasing ratio is due to technological development as a function of time (with a correction due to substitution).

The two models may be compared in numerical terms by interpreting the same scenario projection data. If we use the values for $\delta$ and $\sigma$ shown in Figure 17 and in Table 18 and if we assign $\beta = -\sigma$, then values for $\gamma$ can be calculated from eqn. (55) for exact model equivalence. The calculation shows that $\gamma$ would be between 0.92 and 0.94 for the High scenario projections (Regions I to III) and 0.89 to 0.92 for the Low scenario projections. These values are within the range given earlier (Table 15) for aggregate final energy and are somewhat higher than the historical values for aggregate final energy for these regions given in Table 12. It has been noted, however, that final demand energy has lower $\gamma$s than intermediate input energy in the developed regions (Section 3.2.2). Thus one would expect that the income–GDP elasticities ($\gamma$s) calculated for the nonenergy sector (based on intermediate input energy) would have higher values than the aggregate economy.

## 5.2 The Industry Sector

The ($\delta$, $\sigma$) model of substitution and technological development perhaps most naturally applies to the industry sector. It is here where energy is truly an intermediate input in a production process. Because the industry sector is reasonably well defined and similar in all regions, this application can be made to all regions (except Region VII for which detailed sectoral projections were not made).

As outlined in Section 3.3 and illustrated in Figure 14, we define the industry sector, for analysis purposes here, as the mining, manufacturing, and construction sectors as defined in the MEDEE model. The energy input is taken to be the intermediate input energy excluding feedstocks (which are not substitutable by capital and labor in a way similar to intermediate input energy). The base year and scenario projection data for value added by and energy input to the industry sector are given in detail in Table A.12 and are listed in Table 19.

As defined in Section 3.3, the output $y$ of the industry sector for this analysis is the value added plus payments for energy. The payments for energy have been estimated by using the values for final energy times the appropriate final energy price. The base year (1972 for prices) prices for the industry sector are given in Table 14 of Section 2. We use \$60/kWyr for Region III and \$30/kWyr for all other regions. Values for 2030 are taken to be 2.4 times the Region III and three times base year values for all other regions. The resulting estimates for energy payments are shown in Table 19 for all regions.

The ratio of energy payments to total output is also given in Table 19. We use only the base year values for the application of the ($\delta$, $\sigma$) model, but these ratios are also shown for 2030 for the High and Low scenario projections. The increase in energy share between 1975 and 2030 for the industry sector is significantly different from similar increases examined earlier (Table 16) for the aggregate economies. As can be calculated from the data of Table 19, these shares increased from 33 to 68 percent (High scenario) and from 50 to 95 percent (Low scenario) for the developed Regions I, II, and III. These increases are greater than the aggregate economy increases shown earlier to be from 18 to 35 percent (High) and from 37 to 69 percent (Low). For the developing Regions IV, V, and VI, however, the reverse is true. For both the High and Low scenario projections, these energy shares increase from 2.0 to 2.3 times base year values for the industry sector while for the aggregate economy increases are shown in Table 16 to be 3.0 to 3.8 times. This comparison of the industry sector with the aggregate economy indicates that the industry sector for all regions is relatively similar while the conservation in the developed regions and the huge increase in energy shares projected for the developing regions are primarily due to other than the industry sector (i.e., to agriculture, household, and transportation).

The results of the application of the ($\delta$, $\sigma$) model to the industry sector projections, according to eqn. (50), are illustrated in Figure 18 for the High scenario. In this figure, combinations of $\delta$ and $\sigma$ are plotted that are consistent with the scenario projection data. These results are very similar to Regions I, II, and III for the nonenergy sector (Figure 17). Region II exhibits the largest values of $\delta$ and $\sigma$ while Regions I and III are

TABLE 19 Data for application of ($\delta$, $\sigma$) model to the industry sector in six regions.

| Region | Industry[a] value added ($10^9$ \$) | Final energy[b] (GW) | Energy payments[c] ($10^9$ \$) | Output[d] $y$ ($10^9$ \$) | Energy share[e] |
|---|---|---|---|---|---|
| *1975* | | | | | |
| I (NA) | 478 | 619 | 19 | 497 | 3.7 |
| II (SU/EE) | 429 | 680 | 20 | 449 | 4.5 |
| III (WE/JANZ) | 980 | 651 | 39 | 1,019 | 3.8 |
| IV (LA) | 112 | 101 | 3 | 115 | 2.6 |
| V (Af/SEA) | 81 | 134 | 4 | 85 | 4.7 |
| VI[f] (ME/NAf) | 26 | 22 | 1 | 27 | 2.4 |
| *2030 High scenario* | | | | | |
| I (NA) | 1,997 | 1,466 | 132 | 2,129 | 6.2 |
| II (SU/EE) | 2,756 | 1,956 | 176 | 2,932 | 6.0 |
| III (WE/JANZ) | 4,046 | 1,767 | 254 | 4,300 | 5.9 |
| IV (LA) | 1,499 | 922 | 83 | 1,582 | 5.2 |
| V (Af/SEA) | 1,186 | 1,536 | 138 | 1,324 | 10.4 |
| VI[f] (ME/NAf) | 1,018 | 622 | 56 | 1,074 | 5.2 |
| *2030 Low scenario* | | | | | |
| I (NA) | 1,184 | 1,015 | 91 | 1,275 | 7.2 |
| II (SU/EE) | 1,791 | 1,422 | 128 | 1,919 | 6.7 |
| III (WE/JANZ) | 2,443 | 1,142 | 164 | 2,607 | 6.3 |
| IV (LA) | 849 | 531 | 48 | 897 | 5.3 |
| V (Af/SEA) | 619 | 764 | 69 | 688 | 10.0 |
| VI[f] (ME/NAf) | 447 | 292 | 26 | 473 | 5.6 |

[a] Value added (\$1975) in mining, manufacturing, and construction sectors excluding energy sector (see *f*). Data resulting from detailed scenario projections.
[b] Excluding feedstocks, data from Table A. 12.
[c] Using 1972 base year prices of \$60/kWyr for Region III and \$30/kWyr for all other regions for 1975 (see Table 14) and \$144(2.4 × \$60) for Region III and \$90 (3.0 × \$30) for all other regions for 2030.
[d] The sum of value added and energy payments.
[e] Energy payments expressed as a percentage of output.
[f] The mining sector has been excluded in Region VI.

similar but with much lower values than Region II. The developing Regions IV, V, and VI are grouped together but with still lower values of technological development and substitution.

As in the previous application of this model, we choose specific but arbitrary combinations of $\delta$ and $\sigma$ as shown in Figure 18 and calculate the implied relative prices of energy inputs to nonenergy inputs and increases in requirements for nonenergy inputs due to substitution. For the three developed regions, these results for the industry sector (Table 20) are comparable to those for the entire nonenergy sector as given in Table 18. The additional results for the developing Regions IV, V, and VI indicate somewhat higher energy/nonenergy relative price increases. But the combination of these higher relative prices and lower elasticities of substitution result in estimates for increased use of the nonenergy inputs due to substitution very similar to those for Regions I and III.

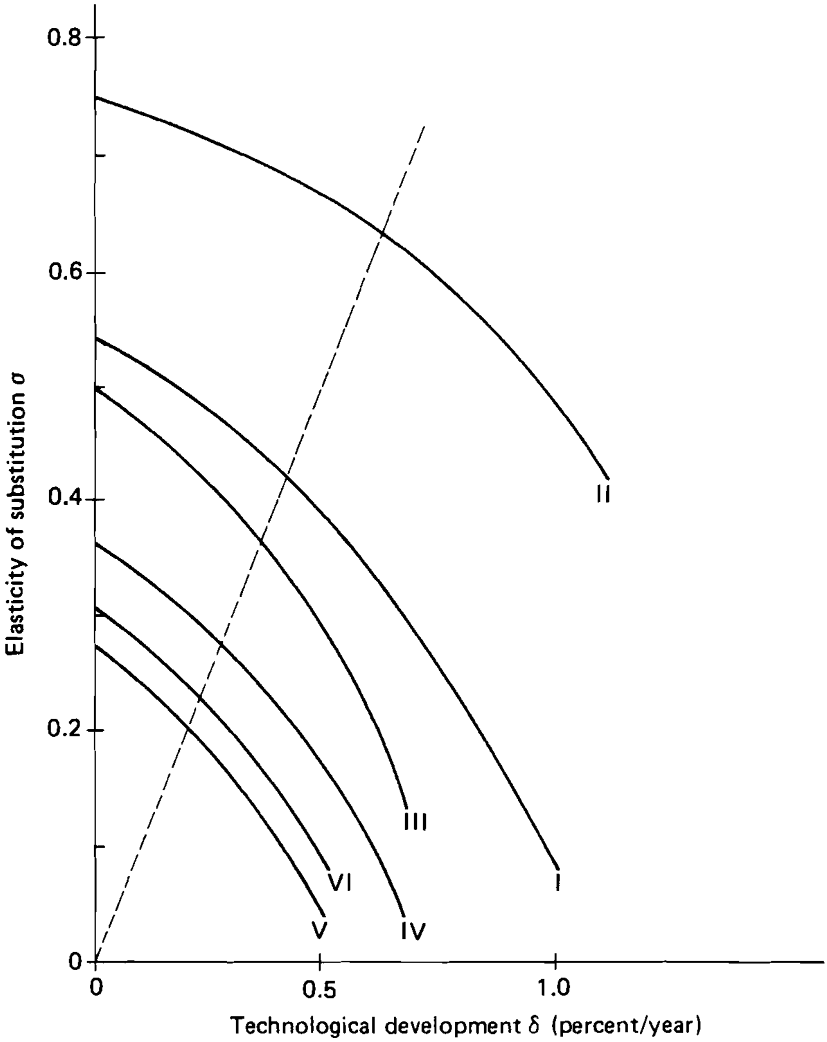



FIGURE 18 Technological development and substitution in industry in the High scenario.

## 5.3 Conclusions

The purpose of the examination of the scenario projections by means of an aggregate model like the ($\delta$, $\sigma$) model was to understand better these projections with respect to energy prices, technological development, and substitution of other factors of production for energy.

As shown in detail earlier in this section, examples of model parameter values that are consistent with the scenario projections for the aggregate nonenergy sector show that technological development may be from about 0.3 to 0.7 percent per year and elasticities of substitution may also be from about 0.3 to 0.7. These values combine with our price assumptions to indicate that technological development may account for from 36 percent

TABLE 20 Application of the ($\delta$, $\sigma$) model to the industry sector[a].

| Region | Technological development $\delta$ (percent/ year) | Elasticity of substitution $\sigma$ | Value share of energy $a$ (percent) | Energy/ nonenergy relative price | Increase in nonenergy inputs (percent) |
|---|---|---|---|---|---|
| *High scenario* | | | | | |
| I (NA) | 0.42 | 0.42 | 3.7 | 2.5 | 1.9 |
| II (SU/EE) | 0.63 | 0.63 | 4.5 | 2.2 | 2.6 |
| III (WE/JANZ) | 0.36 | 0.36 | 3.8 | 2.0 | 1.2 |
| IV (LA) | 0.27 | 0.27 | 2.6 | 2.7 | 1.0 |
| V (Af/SEA) | 0.20 | 0.20 | 4.7 | 2.9 | 1.5 |
| IV[b] (ME/NAf) | 0.22 | 0.22 | 2.4 | 2.8 | 0.8 |
| *Low scenario* | | | | | |
| I (NA) | 0.30 | 0.30 | 3.7 | 2.7 | 1.6 |
| II (SU/EE) | 0.53 | 0.53 | 4.5 | 2.4 | 2.5 |
| III (WE/JANZ) | 0.30 | 0.30 | 3.8 | 2.1 | 1.1 |
| IV (LA) | 0.26 | 0.26 | 2.6 | 2.7 | 1.0 |
| V (Af/SEA) | 0.23 | 0.23 | 4.7 | 2.8 | 1.7 |
| VI[b] (ME/NAf) | 0.18 | 0.18 | 2.4 | 2.8 | 0.7 |

[a]See Table 18 for explanation of column headings.
[b]The mining sector has been excluded from Region VI.

to 46 percent of projected energy conservation with the remainder coming from price-induced substitution.

The primary usefulness of the ($\delta, \sigma$) model is to examine substitution of factors of production. The scenario projections generally assume a significant shift towards more capital-intensive production processes. This shift is most evident in the energy sector itself as documented in Energy Program Group 1981 and Kononov and Por 1979. Shifts to higher capital intensiveness in other resource sectors is also expected, but has not been examined in this work. The shift examined here is the substitution of capital and labor factors of production in place of energy due to projected price increases of energy. As mentioned in Section 3, this effect is a small change in a large sector (the nonenergy sector) whereas the increased capital intensiveness of the energy sector is a large change in a (relatively) small sector.

Based on the ($\delta, \sigma$) model interpretation of the scenario projections, the increase in nonenergy inputs (capital and labor), due to the price increase of energy, is about 1 to 1½ percent in Regions I and III for the nonenergy sector. Much greater shifts were evident in Region II – almost 5 percent. This model, however, did not separate capital and labor as separate inputs; the shifts noted are from energy to some combination of more capital and labor. The split between these two primary inputs would depend on many factors, including relative price changes, not quantified in the scenario projections. Results for the industry sector alone are similar with increases of nonenergy inputs of 0.7 to 1.9 percent in all regions except Region II where the increase was about 2.5 percent.

In summary, with respect to increases in capital intensiveness our projections indicate large increases in the energy sector (documented elsewhere), and significant increases in the aggregate nonenergy sector, as well as the industry sector, due to energy price changes. Other effects, such as changes due to other resource price increases have not been examined.

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## APPENDIX A: RECENT HISTORICAL AND SCENARIO PROJECTION DATA BY REGION 1950–2030

TABLE A. 1 Population by region 1950–1975 ($\times 10^6$).

| Region | 1950 | 1955 | 1960 | 1965 | 1970 | 1975 |
|---|---|---|---|---|---|---|
| I (NA) | 166 | 182 | 199 | 214 | 226 | 237 |
| II (SU/EE) | 268 | 289 | 311 | 331 | 346 | 363 |
| III (WE/JANZ) | 431 | 454 | 479 | 508 | 533 | 560 |
| IV (LA) | 164 | 188 | 216 | 247 | 283 | 319 |
| V (Af/SEA) | 797 | 875 | 980 | 1,110 | 1,258 | 1,422 |
| VI (ME/NAf) | 67 | 76 | 86 | 98 | 114 | 133 |
| VII (C/CPA) | 599 | 648 | 704 | 767 | 836 | 912 |
| World | 2,492 | 2,712 | 2,975 | 3,275 | 3,596 | 3,946 |

SOURCE: C. Doblin, Historical Data Series, September 1979, IIASA WP-79-87.

TABLE A. 2 GDP[a] by region 1950–1975 [$10^9$ US$ (1975)].

| Region | 1950 | 1955 | 1960 | 1965 | 1970 | 1975 |
|---|---|---|---|---|---|---|
| I (NA) | 727 | 893 | 1,008 | 1,270 | 1,487 | 1,670 |
| II (SU/EE) | 135 | 233 | 364 | 491 | 693 | 930 |
| III (WE/JANZ) | 681 | 869 | 1,111 | 1,471 | 1,971 | 2,385 |
| IV (LA) | 86 | 111 | 140 | 182 | 234 | 340 |
| V (Af/SEA) | 104 | 128 | 152 | 189 | 247 | 340 |
| VI (ME/NAf) | 24 | 35 | 47 | 74 | 111 | 190 |
| VII (C/CPA) | 61 | 102 | 132 | 166 | 222 | 320 |
| World | 1,818 | 2,371 | 2,954 | 3,843 | 4,965 | 6,175 |

[a]In constant 1975 US$ using 1975 prices and 1975 official exchange rates. The appropriate US GDP implicit price deflator to convert to 1980 US dollars is 1.41.

SOURCE: C. Doblin, Historical Data Series (see Table A.1) using the following sources: *Yearbook of National Accounts Statistics*, 1976, Vol. II, United Nations, *World Bank Atlas*, 12th edition, 1977, World Bank, *Main Economic Indicators*, OECD, April 1978.

TABLE A. 3 GDP by region 1975–2030 [$10^9$ US$ (1975)].

| Region | High scenario 1975 | 1985 | 2000 | 2015 | 2030 |
|---|---|---|---|---|---|
| I (NA) | 1,670 | 2,535 | 4,126 | 5,889 | 7,926 |
| II (SU/EE) | 930 | 1,515 | 2,729 | 4,571 | 7,658 |
| III (WE/JANZ) | 2,385 | 3,633 | 5,999 | 8,688 | 11,693 |
| IV (LA) | 340 | 620 | 1,272 | 2,193 | 3,569 |
| V (Af/SEA) | 340 | 597 | 1,207 | 2,112 | 3,488 |
| VI (ME/NAf) | 190 | 381 | 900 | 1,668 | 2,918 |
| VII (C/CPA) | 320 | 521 | 939 | 1,573 | 2,450 |
| World | 6,175 | 9,800 | 17,170 | 26,700 | 39,700 |
| Region | Low scenario 1975 | 1985 | 2000 | 2015 | 2030 |
| I (NA) | 1,670 | 2,265 | 3,049 | 3,592 | 4,170 |
| II (SU/EE) | 930 | 1,445 | 2,420 | 3,504 | 4,713 |
| III (WE/JANZ) | 2,385 | 3,260 | 4,452 | 5,566 | 6,656 |
| IV (LA) | 340 | 540 | 918 | 1,430 | 2,229 |
| V (Af/SEA) | 340 | 543 | 924 | 1,398 | 1,995 |
| VI (ME/NAf) | 190 | 328 | 643 | 959 | 1,310 |
| VII (C/CPA) | 320 | 443 | 690 | 999 | 1,345 |
| World | 6,175 | 8,820 | 13,100 | 17,450 | 22,400 |

TABLE A. 4 GDP per capita by region 1950–1975 [US$ (1975)].

| Region | 1950 | 1955 | 1960 | 1965 | 1970 | 1975 |
|---|---|---|---|---|---|---|
| I (NA) | 4,380 | 4,907 | 5,065 | 5,935 | 6,580 | 7,046 |
| II (SU/EE) | 504 | 806 | 1,170 | 1,483 | 2,003 | 2,562 |
| III (WE/JANZ) | 1,580 | 1,914 | 2,319 | 2,896 | 3,698 | 4,259 |
| IV (LA) | 524 | 590 | 648 | 737 | 827 | 1,066 |
| V (Af/SEA) | 130 | 146 | 155 | 170 | 196 | 239 |
| VI (ME/NAf) | 358 | 461 | 547 | 755 | 974 | 1,429 |
| VII (C/CPA) | 102 | 157 | 188 | 216 | 266 | 351 |
| World | 730 | 874 | 993 | 1,173 | 1,381 | 1,565 |

SOURCE: Tables A. 1 and A. 2.

TABLE A. 5 GDP per capita by reigon 1975–2030 [US$ (1975)].

| Region | High scenario 1975 | 1985 | 2000 | 2015 | 2030 |
|---|---|---|---|---|---|
| I (NA) | 7,046 | 9,864 | 14,528 | 19,500 | 25,160 |
| II (SU/EE) | 2,562 | 3,855 | 6,259 | 9,788 | 15,950 |
| III (WE/JANZ) | 4,259 | 5,946 | 8,822 | 11,950 | 15,250 |
| IV (LA) | 1,066 | 1,462 | 2,212 | 3,165 | 4,480 |
| V (Af/SEA) | 239 | 321 | 477 | 686 | 980 |
| VI (ME/NAf) | 1,429 | 2,165 | 3,644 | 5,523 | 8,270 |
| VII (C/CPA) | 351 | 475 | 706 | 1,015 | 1,430 |
| World | 1,565 | 2,035 | 2,820 | 3,750 | 4,980 |
| Region | Low scenario 1975 | 1985 | 2000 | 2015 | 2030 |
| I (NA) | 7,046 | 8,813 | 10,736 | 11,890 | 13,240 |
| II (SU/EE) | 2,562 | 3,677 | 5,550 | 7,503 | 9,820 |
| III (WE/JANZ) | 4,259 | 5,336 | 6,547 | 7,660 | 8,680 |
| IV (LA) | 1,066 | 1,274 | 1,600 | 2,060 | 2,800 |
| V (Af/SEA) | 239 | 292 | 366 | 454 | 560 |
| VI (ME/NAf) | 1,429 | 1,864 | 2,603 | 3,175 | 3,710 |
| VII (C/CPA) | 351 | 404 | 519 | 645 | 780 |
| World | 1,565 | 1,830 | 2,150 | 2,450 | 2,810 |

SOURCE: Table 2 and Table A. 3.

TABLE A. 6 Primary commercial energy consumption[a] by region 1950–1975 (GW).

| Region | 1950 | 1955 | 1960 | 1965 | 1970 | 1975[b] |
|---|---|---|---|---|---|---|
| I (NA) | 1,138 | 1,340 | 1,532 | 1,850 | 2,363 | 2,654 |
| II (SU/EE) | 419 | 631 | 855 | 1,156 | 1,462 | 1,835 |
| III (WE/JANZ) | 665 | 855 | 1,026 | 1,353 | 1,825 | 2,256 |
| IV (LA) | 61 | 92 | 127 | 166 | 247 | 338 |
| V (Af/SEA) | 59 | 86 | 124 | 178 | 266 | 328 |
| VI (ME/NAf) | 10 | 15 | 26 | 35 | 59 | 126 |
| VII (C/CPA) | 33 | 82 | 224 | 202 | 285 | 461 |
| World | 2,385 | 3,101 | 3,914 | 4,940 | 6,507 | 7,998[c] |

[a] Apparent inland consumption for each region (excludes international bunkers). Hydro and nuclear generated electricity counted on primary equivalent basis.

[b] Data for 1975 were compiled from a variety of sources and may not be fully compatible with data for earlier years.

[c] Excludes 210 GW for bunkers.

SOURCE: C. Doblin, Historical Data Series (see Table A. 1) for all regions except Region VII which comes from V. Chant "Scenario Projections for Region VII: China and Centrally Planned Asian Economies", IIASA Working Paper, forthcoming.

TABLE A. 7 Primary commercial energy consumption by region 1975–2030, High and Low scenarios (TW).

| Region | High scenario 1975 | 1985 | 2000 | 2015 | 2030 |
|---|---|---|---|---|---|
| I (NA) | 2.65 | 3.01 | 3.89 | 4.96 | 6.02 |
| II (SU/EE) | 1.84 | 2.48 | 3.69 | 5.23 | 7.33 |
| III (WE/JANZ) | 2.26 | 2.99 | 4.29 | 5.75 | 7.14 |
| IV (LA) | 0.34 | 0.63 | 1.34 | 2.32 | 3.68 |
| V (Af/SEA) | 0.33 | 0.64 | 1.43 | 2.70 | 4.65 |
| VI (ME/NAf) | 0.13 | 0.30 | 0.77 | 1.47 | 2.38 |
| VII (C/CPA) | 0.46 | 0.78 | 1.44 | 2.54 | 4.45 |
| World | 8.21[a] | 10.83 | 16.83 | 24.97 | 35.65 |

| Region | Low scenario 1975 | 1985 | 2000 | 2015 | 2030 |
|---|---|---|---|---|---|
| I (NA) | 2.65 | 2.83 | 3.31 | 3.68 | 4.37 |
| II (SU/EE) | 1.84 | 2.30 | 3.31 | 4.15 | 5.00 |
| III (WE/JANZ) | 2.26 | 2.69 | 3.39 | 3.97 | 4.54 |
| IV (LA) | 0.34 | 0.56 | 0.97 | 1.53 | 2.31 |
| V (Af/SEA) | 0.33 | 0.57 | 1.07 | 1.75 | 2.66 |
| VI (ME/NAf) | 0.13 | 0.27 | 0.56 | 0.90 | 1.23 |
| VII (C/CPA) | 0.46 | 0.63 | 0.98 | 1.51 | 2.29 |
| World | 8.21[a] | 9.85 | 13.59 | 17.50 | 22.39 |

[a]Including 0.21 TW for international bunkers.
SOURCE: IIASA ENP.

TABLE A. 8 Primary energy consumption per capita by region 1950–1975 (kW/cap).

| Region | 1950 | 1955 | 1960 | 1965 | 1970 | 1975[a] |
|---|---|---|---|---|---|---|
| I (NA) | 6.9 | 7.4 | 7.7 | 8.6 | 10.5 | 11.2 |
| II (SU/EE) | 1.6 | 2.2 | 2.7 | 3.5 | 4.2 | 5.1 |
| III (WE/JANZ) | 1.5 | 1.9 | 2.1 | 2.7 | 3.5 | 4.0 |
| IV (LA) | 0.36 | 0.47 | 0.57 | 0.67 | 0.87 | 1.06 |
| V (Af/SEA) | 0.07 | 0.10 | 0.13 | 0.16 | 0.21 | 0.23 |
| VI (ME/NAf) | 0.15 | 0.20 | 0.30 | 0.36 | 0.52 | 0.95 |
| VII (C/CPA) | 0.06 | 0.13 | 0.32 | 0.26 | 0.34 | 0.51 |
| World | 0.97 | 1.14 | 1.31 | 1.51 | 1.81 | 2.08 |

[a]See [b] Table A. 6 and [a] Table A. 7.
SOURCE: Tables A. 1 and A. 6.

TABLE A. 9 Primary energy consumption per capita by region 1975–2030 (kW/cap).

| Region | High scenario 1975 | 1985 | 2000 | 2015 | 2030 |
|---|---|---|---|---|---|
| I (NA) | 11.2 | 11.7 | 13.7 | 16.4 | 19.1 |
| II (SU/EE) | 5.0 | 6.3 | 8.5 | 11.2 | 15.3 |
| III (WE/JANZ) | 4.0 | 4.9 | 6.3 | 7.9 | 9.3 |
| IV (LA) | 1.1 | 1.5 | 2.3 | 3.3 | 4.6 |
| V (Af/SEA) | .23 | .34 | .56 | .88 | 1.3 |
| VI (ME/NAf) | .95 | 1.69 | 3.11 | 4.87 | 6.74 |
| VII (C/CPA) | .51 | .71 | 1.08 | 1.64 | 2.60 |
| World | 2.08 | 2.25 | 2.77 | 3.50 | 4.47 |
| Region | Low scenario 1975 | 1985 | 2000 | 2015 | 2030 |
| I (NA) | 11.2 | 11.0 | 11.7 | 12.2 | 13.9 |
| II (SU/EE) | 5.0 | 5.9 | 7.6 | 8.7 | 10.4 |
| III (WE/JANZ) | 4.0 | 4.4 | 5.0 | 5.4 | 5.9 |
| IV (LA) | 1.1 | 1.3 | 1.7 | 2.2 | 2.9 |
| V (Af/SEA) | .23 | .31 | .42 | .57 | .75 |
| VI (ME/NAf) | .95 | 1.52 | 2.28 | 2.99 | 3.48 |
| VII (C/CPA) | .51 | .58 | .74 | .98 | 1.34 |
| World | 2.08 | 2.05 | 2.24 | 2.46 | 2.81 |

SOURCE: Table 2 and Table A. 7.

TABLE A. 10 Final commercial energy[a] by region 1950–1975 (GW).

| Region | 1950 | 1955 | 1960 | 1965 | 1970 | 1975[b] |
|---|---|---|---|---|---|---|
| I (NA) | 960 | 1,087 | 1,206 | 1,430 | 1,787 | 1,871 |
| II (SU/EE) | 359 | 531 | 704 | 922 | 1,138 | 1,277 |
| III (WE/JANZ) | 549 | 690 | 796 | 1,013 | 1,336 | 1,588 |
| IV (LA) | 49 | 73 | 100 | 133 | 191 | 255 |
| V (Af/SEA) | 50 | 71 | 104 | 147 | 212 | 253 |
| VI (ME/NAf) | 9 | 13 | 22 | 29 | 48 | 106 |
| VII (C/CPA) | 30 | 73 | 193 | 168 | 244 | 393 |
| World | 2,006 | 2,538 | 3,125 | 3,842 | 4,956 | 5,743 |

[a]Data for 1950–1970 are estimated from primary energy statistics accounting for average losses and electricity conversion.

[b]Data for 1975 were compiled from a variety of sources and may not be fully compatible with data for earlier years.

TABLE A. 11 Final commercial energy[a] by region 1975–2030, High and Low scenarios (GW).

| Region | High scenario 1975 | 1985 | 2000 | 2015 | 2030 |
|---|---|---|---|---|---|
| I (NA) | 1,871 | 2,130 | 2,628 | 3,181 | 3,665 |
| II (SU/EE) | 1,277 | 1,702 | 2,387 | 3,122 | 4,114 |
| III (WE/JANZ) | 1,589 | 2,195 | 3,035 | 3,769 | 4,375 |
| IV (LA) | 255 | 486 | 1,005 | 1,700 | 2,641 |
| V (Af/SEA) | 253 | 497 | 1,063 | 1,916 | 3,174 |
| VI (ME/NAf) | 106 | 231 | 578 | 1,041 | 1,638 |
| VII (C/CPA) | 393 | 675 | 1,234 | 2,091 | 3,196 |
| World | 5,744 | 7,916 | 11,930 | 16,820 | 22,800 |
| Region | Low scenario 1975 | 1985 | 2000 | 2015 | 2030 |
| I (NA) | 1,871 | 2,015 | 2,257 | 2,460 | 2,636 |
| II (SU/EE) | 1,277 | 1,617 | 2,171 | 2,616 | 2,952 |
| III (WE/JANZ) | 1,589 | 1,963 | 2,393 | 2,738 | 2,988 |
| IV (LA) | 255 | 425 | 733 | 1,119 | 1,656 |
| V (Af/SEA) | 253 | 442 | 802 | 1,287 | 1,877 |
| VI (ME/NAf) | 106 | 205 | 434 | 649 | 868 |
| VII (C/CPA) | 393 | 548 | 845 | 1,217 | 1,589 |
| World | 5,744 | 7,215 | 9,635 | 12,090 | 14,570 |

[a] Including feedstocks.

TABLE A. 12 Final energy consumption by sector 1975 - 2030, Region I (NA) (GWyr/yr).

| Sector | 1975 | High scenario 1985 | 2000 | 2015 | 2030 | Low scenario 1985 | 2000 | 2015 | 2030 |
|---|---|---|---|---|---|---|---|---|---|
| Agriculture | 34 | 47 | 64 | 78 | 88 | 42 | 52 | 56 | 61 |
| Industry[a] | 619 | 785 | 1,031 | 1,260 | 1,466 | 730 | 852 | 934 | 1,015 |
| Service | 162 | 172 | 201 | 226 | 248 | 158 | 166 | 173 | 179 |
| Transportation | 541 | 546 | 651 | 836 | 1,013 | 522 | 560 | 625 | 684 |
| of which, passenger | (398) | (334) | (314) | (365) | (392) | (330) | (304) | (325) | (338) |
| Households | 411 | 432 | 464 | 493 | 495 | 428 | 450 | 467 | 462 |
| Total commercial final (excl. feedstocks) | 1,768 | 1,983 | 2,410 | 2,894 | 3,309 | 1,880 | 2,080 | 2,254 | 2,401 |
| Feedstocks | 104 | 147 | 218 | 287 | 355 | 136 | 177 | 206 | 235 |
| Total commercial final (incl. feedstocks) | 1,871 | 2,130 | 2,628 | 3,181 | 3,665 | 2,015 | 2,257 | 2,460 | 2,636 |
| Noncommercial[b] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

[a]Mining, manufacturing, and construction.
[b]Firewood, animal waste, etc.

TABLE A. 12 Final energy consumption by sector 1975–2030, Region II (SU/EE) (GWyr/yr).

| Sector | 1975 | High scenario 1985 | 2000 | 2015 | 2030 | Low scenario 1985 | 2000 | 2015 | 2030 |
|---|---|---|---|---|---|---|---|---|---|
| Agriculture | 28 | 38 | 52 | 65 | 72 | 38 | 55 | 70 | 82 |
| Industry[a] | 680 | 892 | 1,212 | 1,515 | 1,956 | 847 | 1,117 | 1,308 | 1,422 |
| Service | 73 | 94 | 135 | 185 | 241 | 87 | 116 | 139 | 159 |
| Transportation | 224 | 297 | 418 | 569 | 786 | 283 | 376 | 463 | 549 |
| of which, passenger | (56) | (86) | (125) | (169) | (213) | (77) | (105) | (131) | (152) |
| Households | 220 | 272 | 348 | 410 | 449 | 265 | 326 | 372 | 392 |
| Total commercial final (excl. feedstocks) | 1,225 | 1,592 | 2,165 | 2,745 | 3,504 | 1,519 | 1,990 | 2,351 | 2,604 |
| Feedstocks | 51 | 110 | 222 | 377 | 610 | 98 | 180 | 265 | 348 |
| Total commercial final (incl. feedstocks) | 1,277 | 1,702 | 2,387 | 3,122 | 4,114 | 1,617 | 2,171 | 2,616 | 2,952 |
| Noncommercial[b] | 44 | 44 | 44 | 44 | 44 | 44 | 44 | 44 | 44 |

[a]Mining, manufacturing and construction.
[b]Fire wood, animal waste, etc.

TABLE A. 12 Final energy consumption by sector 1975–2030, Region III (WE/JANZ) (GWyr/yr).

| Sector | 1975 | High scenario 1985 | 2000 | 2015 | 2030 | Low scenario 1985 | 2000 | 2015 | 2030 |
|---|---|---|---|---|---|---|---|---|---|
| Agriculture | 27 | 39 | 53 | 62 | 58 | 34 | 39 | 41 | 39 |
| Industry[a] | 651 | 876 | 1,217 | 1,513 | 1,767 | 783 | 927 | 1,047 | 1,142 |
| Service | 68 | 81 | 114 | 148 | 188 | 75 | 100 | 121 | 144 |
| Transportation | 313 | 475 | 708 | 932 | 1,114 | 406 | 526 | 624 | 689 |
| of which, passenger | (188) | (289) | (415) | (530) | (604) | (241) | (307) | (360) | (384) |
| Households | 403 | 542 | 664 | 747 | 806 | 501 | 592 | 658 | 696 |
| Total commercial final (excl. feedstocks) | 1,462 | 2,012 | 2,756 | 3,402 | 3,933 | 1,799 | 2,183 | 2,491 | 2,710 |
| Feedstocks | 126 | 183 | 279 | 367 | 443 | 164 | 210 | 247 | 278 |
| Total commercial final (incl. feedstocks) | 1,589 | 2,195 | 3,035 | 3,769 | 4,375 | 1,963 | 2,393 | 2,738 | 2,988 |
| Noncommercial[b] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

[a] Mining, manufacturing, and construction.
[b] Fire wood, animal waste, etc.

TABLE A. 12 Final energy consumption by sector 1975–2030. Region IV (LA) (GWyr/yr).

| Sector | 1975 | High scenario 1985 | 2000 | 2015 | 2030 | Low scenario 1985 | 2000 | 2015 | 2030 |
|---|---|---|---|---|---|---|---|---|---|
| Agriculture | 1 | 4 | 13 | 27 | 40 | 4 | 12 | 24 | 36 |
| Industry[a] | 101 | 193 | 382 | 625 | 922 | 163 | 259 | 378 | 531 |
| Service | 3 | 6 | 14 | 24 | 38 | 6 | 12 | 24 | 42 |
| Transportation | 105 | 195 | 410 | 713 | 1,154 | 172 | 304 | 473 | 716 |
| of which, passenger | (32) | (61) | (133) | (243) | (402) | (55) | (105) | (174) | (277) |
| Households | 28 | 51 | 98 | 148 | 217 | 49 | 88 | 123 | 169 |
| Total commercial final (excl. feedstocks) | 238 | 449 | 915 | 1,537 | 2,372 | 394 | 674 | 1,023 | 1,503 |
| Feedstocks | 17 | 37 | 89 | 163 | 268 | 31 | 58 | 96 | 153 |
| Total commercial final (incl. feedstocks) | 254 | 486 | 1,004 | 1,699 | 2,640 | 425 | 733 | 1,119 | 1,656 |
| Noncommercial[b] | 109 | 109 | 109 | 109 | 109 | 109 | 109 | 109 | 109 |

[a] Mining, manufacturing and construction.
[b] Fire wood, animal waste, etc.

TABLE A. 12 Final energy consumption by sector 1975–2030, Region V (Af/SEA) (GWyr/yr).

| | | High scenario | | | | Low scenario | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sector | 1975 | 1985 | 2000 | 2015 | 2030 | 1985 | 2000 | 2015 | 2030 |
| Agriculture | 4 | 18 | 56 | 123 | 188 | 17 | 50 | 104 | 154 |
| Industry[a] | 134 | 265 | 258 | 949 | 1,536 | 228 | 375 | 561 | 764 |
| Service | 2 | 5 | 15 | 30 | 47 | 5 | 11 | 19 | 28 |
| Transportation | 76 | 130 | 274 | 520 | 909 | 121 | 224 | 380 | 607 |
| of which, passenger | (32) | (54) | (124) | (266) | (499) | (51) | (106) | (204) | (358) |
| Households | 25 | 54 | 106 | 167 | 251 | 50 | 102 | 154 | 219 |
| Total commercial final (excl. feedstocks) | 242 | 472 | 999 | 1,788 | 2,931 | 421 | 762 | 1,219 | 1,772 |
| Feedstocks | 11 | 25 | 63 | 128 | 242 | 21 | 40 | 68 | 104 |
| Total commercial final (incl. feedstocks) | 253 | 497 | 1,063 | 1,915 | 3,173 | 442 | 802 | 1,287 | 1,876 |
| Noncommercial[b] | 344 | 344 | 344 | 344 | 344 | 344 | 344 | 344 | 344 |

[a] Mining, manufacturing, and construction.
[b] Fire wood, animal waste, etc.

TABLE A. 12 Final energy consumption by sector 1975–2030, Region VI (ME/NAf) (GWyr/yr).

| | | High scenario | | | | Low scenario | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sector | 1975 | 1985 | 2000 | 2015 | 2030 | 1985 | 2000 | 2015 | 2030 |
| Agriculture | 1 | 2 | 8 | 16 | 26 | 2 | 7 | 13 | 20 |
| Industry[a] | 40 | 101 | 261 | 459 | 670 | 90 | 193 | 270 | 334 |
| Service | 1 | 3 | 11 | 27 | 55 | 3 | 10 | 18 | 35 |
| Transportation | 42 | 82 | 200 | 363 | 612 | 68 | 143 | 225 | 314 |
| of which, passenger | (8) | (18) | (47) | (102) | (209) | (16) | (37) | (64) | (105) |
| Households | 14 | 24 | 49 | 79 | 120 | 24 | 44 | 65 | 88 |
| Total commercial final (excl. feedstocks) | 97 | 213 | 530 | 944 | 1,482 | 187 | 396 | 591 | 791 |
| Feedstocks | 9 | 19 | 48 | 97 | 155 | 19 | 38 | 57 | 77 |
| Total commercial final (incl. feedstocks) | 106 | 231 | 578 | 1,041 | 1,638 | 205 | 434 | 649 | 868 |
| Noncommercial[b] | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

[a] Mining, manufacturing and construction.
[b] Fire wood, animal waste, etc.

TABLE A. 12 Final energy consumption by sector 1975–2030, Region VII (C/CPA) (GWyr/yr).

| Sector | 1975 | High scenario 1985 | 2000 | 2015 | 2030 | Low scenario 1985 | 2000 | 2015 | 2030 |
|---|---|---|---|---|---|---|---|---|---|
| Agriculture<br>Industry[a] | 232 | | | | | | | | |
| Service | | | | | | | | | |
| Transportation | 31 | | | | | | | | |
| of which, passenger | | | | | | | | | |
| Households | 117 | | | | | | | | |
| Total commercial final[c] (excl. feedstocks) | 380 | 650 | 1,178 | 1,976 | 2,996 | 528 | 810 | 1,157 | 1,499 |
| Feedstocks[d] | 13 | 25 | 56 | 115 | 200 | 20 | 35 | 60 | 90 |
| Total commercial final (incl. feedstocks) | 393 | 675 | 1,234 | 2,091 | 3,196 | 548 | 845 | 1,217 | 1,589 |
| Noncommercial[b] | | | | | | | | | |

[a] Mining, manufacturing, and construction.
[b] Fire wood, animal waste, etc.
[c] Excluding feedstocks.
[d] Estimated on cross-regional GDP per capita basis.

TABLE A. 13 Electricity consumption as a fraction of final energy[a] by region 1950–2030 (percent).

| Region | Historical 1950 | 1975 | High scenario 2000 | 2030 | Low scenario 2000 | 2030 |
|---|---|---|---|---|---|---|
| I (NA) | 4.5 | 13.0 | 21.8 | 26.7 | 22.4 | 27.9 |
| II (SU/EE) | 3.6 | 9.2 | 16.1 | 22.9 | 15.2 | 21.6 |
| III (WE/JANZ) | 5.8 | 13.8 | 19.2 | 25.6 | 20.0 | 26.3 |
| IV (LA) | 5.3 | 7.0 | 11.8 | 16.7 | 11.0 | 16.1 |
| V (Af/SEA) | 3.2 | 3.8 | 8.6 | 14.2 | 7.2 | 10.8 |
| VI (ME/NAf) | 3.3 | 5.2 | 7.8 | 11.9 | 7.8 | 11.0 |
| VII (C/CPA) | 1.3 | 3.7 | 4.8 | 6.3 | 4.8 | 6.3 |
| World | 4.6 | 11.1 | 16.1 | 19.8 | 16.4 | 20.3 |

[a] Electricity consumed by the user (which is typically 85 percent of generation) computed as a fraction of final energy excluding feedstocks.

## APPENDIX B: THE SEVEN WORLD REGIONS OF THE IIASA ENERGY PROGRAM

### Region I: North America (NA)

Highly developed market economies with energy resources.

Canada
United States of America

### Region II: The Soviet Union and Eastern Europe (SU/EE)

Highly developed centrally planned economies with energy resources.

Albania
Bulgaria
Czechoslovakia
German Democratic Republic
Hungary
Poland
Romania
Union of Soviet Socialist Republics

### Region III: W. Europe, Japan, Austrialia, New Zealand, South Africa, and Israel (WE/JANZ)

Highly developed market economies with relatively low energy resources.

*Member Countries of the European Community*

- Belgium
- Denmark
- France
- Germany, Federal Republic of
- Ireland
- Italy
- Luxemburg
- Netherlands
- United Kingdom

*Other Western European Countries*

- Austria
- Cyprus
- Finland
- Greece
- Iceland
- Norway
- Portugal
- Spain
- Sweden
- Switzerland
- Turkey
- Yugoslavia

*Others*

- Australia
- Israel
- Japan
- New Zealand
- South Africa

### Region IV: Latin America (LA)

Developing economies with some energy resources and significant population growth.

- Argentina
- Bahamas
- Belize
- Bolivia
- Brazil
- Chile
- Colombia
- Costa Rica
- Cuba
- Dominican Republic
- Ecuador
- El Salvador
- Guadeloupe
- Guatemala
- Guyana
- Haiti
- Honduras
- Jamaica
- Martinique
- Mexico
- Netherlands Antilles
- Nicaragua
- Panama
- Paraguay
- Peru
- Puerto Rico
- Surinam
- Trinidad and Tobago
- Uruguay
- Venezuela
- Other Caribbean

**Region V: Africa (Except Northern Africa and South Africa), South and Southeast Asia (Af/SEA)**

Slowly developing economies with some energy resources and significant population growth.

*Africa*

Angola
Benin
Botswana
Burundi
Cameroon
Cape Verde
Central African Republic
Chad
Congo
Ethiopia
Gabon
Gambia
Ghana
Guinea
Guinea Bissau
Ivory Coast
Kenya
Lesotho
Liberia
Madagascar
Malawi
Mali
Malta
Mauritania
Mauritius
Morocco
Mozambique
Namibia
Niger
Nigeria
Reunion
Rwanda
Senegal
Sierra Leone
Somalia
Sudan
Swaziland
Tanzania, United Republic of
Togo
Tunisia
Uganda
Upper Volta
Western Sahara
Zaire
Zambia
Zimbabwe

*Asia*

Afghanistan
Bangladesh
Brunei
Burma
Comoros
Hong Kong
India
Indonesia
Korea, Republic of (South)
Macau
Malaysia
Nepal
Pakistan
Papua New Guinea
Philippines
Singapore
Sri Lanka
Taiwan
Thailand
East Timor
West South Asia n.e.s.

### Region VI: Middle East and Northern Africa (ME/NAf)

Developing economies with large energy resources.

*Member Countries of the Organization of Arab Petroleum Exporting Countries (OAPEC)*

Algeria
Bahrain
Egypt
Iraq
Kuwait
Libyan Arab Republic
Qatar
Saudi Arabia
Syrian Arab Republic
United Arab Emirates

*Others*

Iran
Jordan
Lebanon
Oman
Yemen
Yemen, People's Democratic Republic of

### Region VII: China and Centrally Planned Asian Economies (C/CPA)

Developing centrally planned economies with energy resources.

China, People's Republic of
Kampuchea, Democratic (formerly Cambodia)
Korea, Democratic Republic of
Laos, People's Democratic Republic of
Mongolia
Viet-Nam, Socialist Republic of

## APPENDIX C: ENERGY UNITS AND CONVERSION FACTORS

*Abbreviation*

k = kilo $10^3$
M = mega $10^6$
G = giga $10^9$
T = tera $10^{12}$

kWh = kilowatt-hour
kWyr = kilowatt-year (8760 kWh)
BTU = British Thermal Unit
cal = calorie
J = joule

*Energy Units* – exact but rounded

| | | | | | |
|---|---|---|---|---|---|
| 1 kWh | = | 3413 BTU | $10^6$ BTU | = | 293 kWh |
| 1 kWyr | = | $29.9 \cdot 10^6$ BTU | $10^6$ BTU | = | 0.0334 kWyr |
| 1 kWh | = | 860 kcal | $10^6$ kcal | = | 1163 kWh |
| 1 kWyr | = | 0.0982 kcal | $10^6$ kcal | = | 0.133 kWyr |
| 1kJ | = | 0.948 BTU | 1 BTU | = | 1.055 kJ |

*Weight and Volume Units of Energy Products* – approximate

Coal – metric ton (1000 kg) of coal equivalent (mtce)
1 mtce is defined as $7.00 \cdot 10^6$ kcal
which is $27.78 \cdot 10^6$ BTU or 0.929 kWyr

Oil* – barrel (bbl), metric ton of oil equivalent (mtoe)
1 bbl oil is defined as $5.80 \cdot 10^6$ BTU which is 0.194 kWyr
$1.10^6$ bbl/day is then 70.83 GW
1 mtoe is defined as 7.30 bbl which is 1.417 kWyr

Gas – cubic meter ($m^3$)
1 $ft^3$ natural gas is defined as 1000 BTU
1 $m^3$ natural gas is then $0.0353 \cdot 10^6$ BTU or 1.18 kWyr

| | | | | | |
|---|---|---|---|---|---|
| $1 \cdot 10^{12}$ BTU | = | 0.0334 GWyr | 1 GWyr | = | $29.9 \cdot 10^{12}$ BTU |
| $1 \cdot 10^6$ mtce | = | 0.929 GWyr | 1 GWyr | = | $1.076 \cdot 10^6$ mtce |
| $1 \cdot 10^6$ mtoe | = | 1.417 GWyr | 1 GWyr | = | $0.706 \cdot 10^6$ mtoe |
| $1 \cdot 10^6$ bbl | = | 0.194 GWyr | 1 GWyr | = | $5.15 \cdot 10^6$ bbl |
| $1 \cdot 10^9$ $m^3$ n.g. | = | 1.18 GWyr | 1 GWyr | = | $0.847 \cdot 10^9$ $m^3$ n.g. |
| $1 \cdot 10^6$ bbl/day | = | 70.8 GW | 1 GW | = | $0.014 \cdot 10^6$ bbl/day |

*World average crude S.G. 0.86 or API33.

# THE AUTHOR

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