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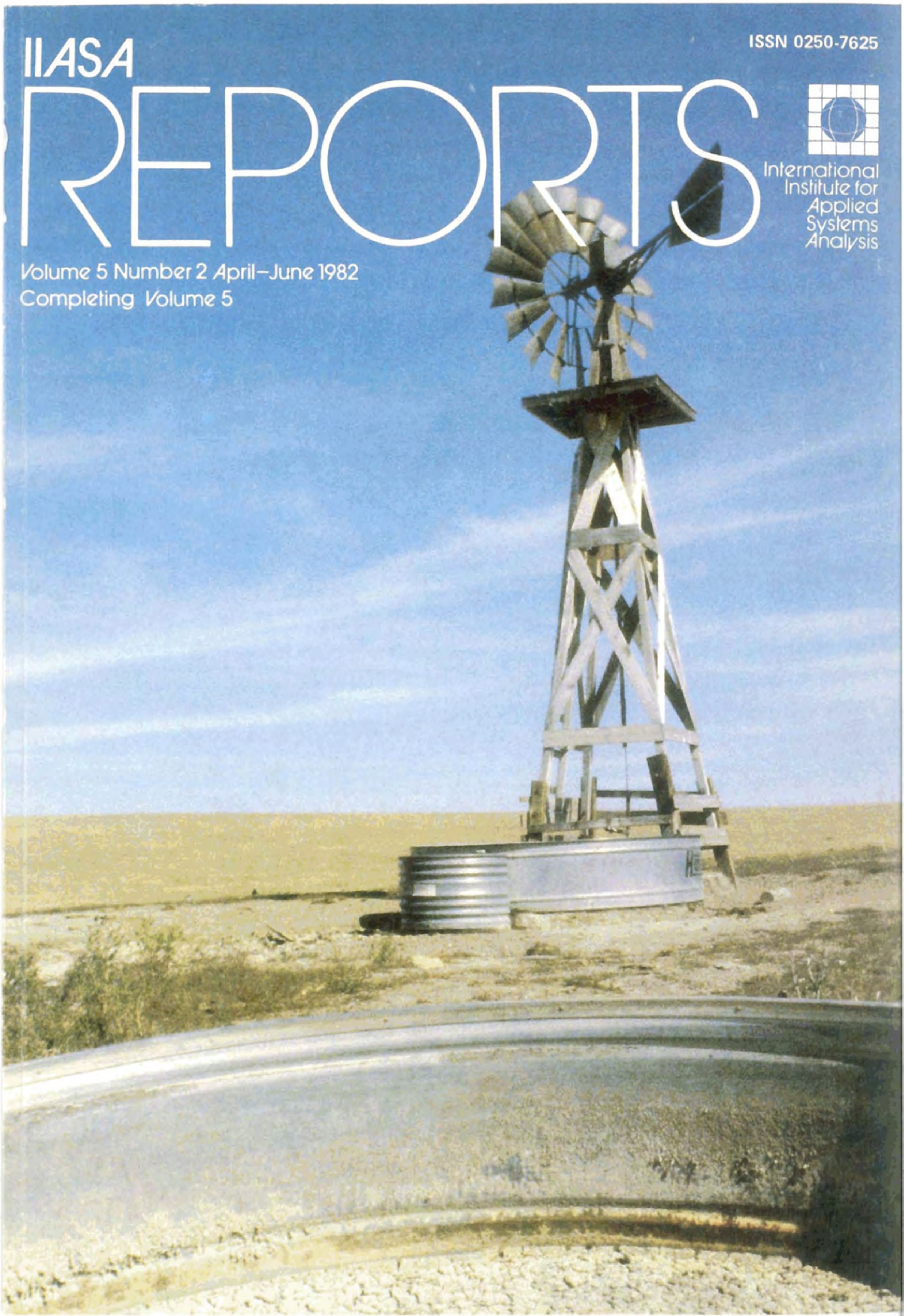

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**Cover**

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# A LONG-TERM MACROECONOMIC EQUILIBRIUM MODEL FOR THE EUROPEAN COMMUNITY

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## SUMMARY

*As fossil fuel reserves become scarcer, the rising cost of energy imports, the diversion of capital to the energy sector, and the general drain of resources to energy-exporting countries will affect economic growth, employment rates, personal consumption rates, and investment behavior in energy-importing countries. Thus the problem of meeting energy requirements involves economic issues as much as the physical availability of resources. MACRO, a highly aggregated, long-term, two-sector general equilibrium model, was developed to examine the energy–economy linkage in the context of the global energy study undertaken by the Energy Systems Program Group of IIASA.*

*This report presents a version of MACRO calibrated for the European Community (EC), focusing on model structure, model validation and testing, and four applications to the EC region over a fifty-year planning period. The applications, based on a range of energy supply scenarios, examine such economic questions as the impact of rising energy costs on economic activity, the feasibility of common assumptions about price-induced conservation, and the impact of continued high levels of energy imports on the trade balance.*

*In essence, MACRO describes supply-constrained economic activity, using energy as the constrained input factor. The model is built around a constant elasticity of substitution (CES) production function, which represents substitution processes among capital, labor, and energy. MACRO differs from similar models of energy–economy interactions through its use of explicit factor functions and an empirically based procedure for estimating the CES production function's parameters. To overcome the problem of long-term extrapolations of econometric functions, which were estimated using data from a relatively short sample period, the model concentrates on slowly changing variables, including the capital: output ratio, investment and consumption rates, population, and the labor force. The model also contains exogenously determined "scenario parameters", which can be used to countervail short-term trends inherent in the estimated parameters, as well as to simulate policy measures.*

*Validation of model results against empirical data shows a satisfactory fit of model output to data for the EC over the period 1966–1976. The model has a slight tendency to underestimate developments during periods of rapid economic growth and to overestimate* *the evolution of economic variables during periods of stagnation or recession. A second type of validation run, simulating an energy crisis in 1965, produces a good replication of the adjustment process that followed the 1973/1974 energy shock. The model results do not, however, account for the low employment rates and high market interest rates that characterized the 1970s.*

*The first long-term application of MACRO to the EC examines the economic impact of continued "business as usual" in the energy sector, i.e., unlimited availability of energy at reasonable costs, an unchanged energy demand–supply structure, and constant capital requirements per unit of production. This rather overoptimistic scenario constitutes a reference case for comparison with less favorable energy supply futures. The results of the MACRO run for Scenario 1 include a slowdown in the growth of gross national product and an accompanying decrease in secondary energy demand.*

*In Scenario 2, energy imports are assumed to be restricted, with correspondingly higher energy import prices. Compared with energy output for the "business as usual" scenario, model results indicate significantly lower economic growth rates, higher equilibrium energy prices, and a marked fall in the real wage rate.*

*The third scenario focuses on the compatibility of high economic growth rates with combined low growth in energy demand and high energy prices. The results of this "consistency check" indicate that the prices commonly assumed to induce a given level of energy conservation are considerably lower than the prices that would actually be required.*

*Scenario 4 analyzes the economic repercussions of the capital deepening that is associated with the creation of an advanced energy supply infrastructure. The impact of the energy sector's rapidly increasing capital: output ratio on interest rates and capital profitability is examined in two successive model runs: the first run, assuming no government intervention on the capital market, indicates that the energy sector would not be able to accumulate sufficient capital; the second run suggests that income tax increases could be used to reduce personal consumption and rechannel investments into the energy sector.*

*One model result common to all four scenarios is a deteriorating balance of trade for the EC over the next several decades. A final MACRO run suggests that if exports were increased sufficiently, the trade balance could be eliminated. However, this would require strong government measures to stimulate economic activity, especially during times of recession.*

## 1 INTRODUCTION

*Energy Transitions*

Because the dynamics of any infrastructure are inherently long-term in nature, an analysis focusing on the implications of structural change requires a far look into the future, as well as into the past. The Energy Systems Program at the International Institute for Applied Systems Analysis has concentrated on the long-term aspects of the energy problem, specifically on the transition (or structural change) from the present global energy system, based mainly on fossil fuels, to a more advanced and, in the long run, sustainable system.

Several similar transition processes have been observed during the last two centuries. Figure 1, taken from Marchetti and Nakićenović (1979), shows the substitution of oil and gas for wood and coal during the nineteenth and twentieth centuries. Historically, these dynamic transitions within the energy sector have followed the development course of the entire economy: an adequate energy supply system has been a prerequisite for industrial development, economic growth, and human prosperity.

Until the middle of the nineteenth century, the world's energy supply was dominated by wood. When heavy machinery and power-assisted tools were introduced into production processes in northern regions of the globe during the industrial revolution, energy sources were needed that had a higher specific energy density and that could be more easily transported over long distances. Coal fulfilled these prerequisites and therefore penetrated into the energy market. Later, consecutive transitions to oil and gas took place for similar reasons.

Of interest to the energy analyst are the regularities characterizing past transitions. The market penetration curves of the new types of energy shown in Figure 1 have almost identical slopes. This observation suggests that the speed of introduction of new energy supply technologies (in fact a change in infrastructure) follows certain inherent laws. One may be directly derived from Figure 1 and applied to future structural shifts in the energy sector: each new technology has required from 70 to 90 years to capture 50% of the global

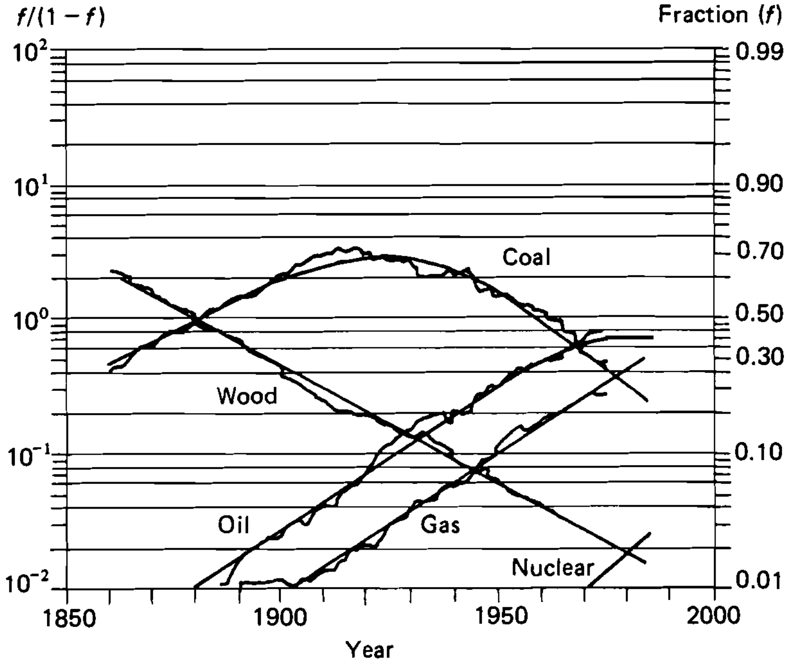

FIGURE 1 Global primary energy substitution. Logarithmic plot of the transformation $f(1-f)$ where $f$ is the fractional market share. Smooth lines are model estimates of historical data; scattered lines are historical data; straight lines show the logistic model substitution paths.

SOURCE: Marchetti and Nakićenović (1978).

energy market, after achieving 1% penetration. On the level of a regional or a national economy, the time required to win a 50% market share is somewhat shorter – roughly 50 years. For this reason, in part, IIASA's Energy Systems Program foresees an energy transition period spanning at least the next 50 years.

### *The Energy Problem in a Global Context*

In recent years, numerous national energy studies have assessed domestic energy demand and calculated energy supply strategies to meet the demand. These strategies describe in detail the domestic energy supply sector and the evolution required for its adaptation to the economy's future energy needs. Most of these studies indicate a gap between energy demand and energy supply; to close the gap, it has been common practice to refer to energy imports and to assume that unlimited amounts of imported energy will be available – without considering the feasibility of this assumption in the international context. When a global approach is taken, however, it is no longer possible to assume an imaginary source from which required imports can be obtained, or an imaginary market to which exports can be directed. Any really feasible long-term energy strategy automatically requires a balanced world trade market. The IIASA study is designed to examine the energy problem on this global scale.

Because energy resources, as well as energy supply and demand patterns, are not equally distributed throughout the world, the globe is divided into seven regions in the IIASA study; the composition of each region is not necessarily based on geographical proximity, but rather reflects similarities in economic structure, energy resource availability, or lifestyle patterns. (See Energy Systems Program Group of IIASA 1981.)

### *The IIASA Set of Energy Models*

In the IIASA study, such attributes as economic activity, energy demand, domestic energy supply, and energy trade volumes had to be determined for each of the seven world regions, and interactions among the regions had to be described as well. This complex configuration required the handling and processing of a very large quantity of data and information within a consistent numerical framework. A set of mathematical models was developed for this purpose as part of the study; a full description of the design and application of the models to the seven world regions is given in Basile (1980) and Energy Systems Program Group of IIASA (1981).

Figure 2 illustrates the interactions and the information flows among the components of the model set. Within this set, the function of MACRO is to provide internal consistency between economic growth and such factors as energy demand and supply, energy imports, energy cost functions, and resource requirements (capital and labor) for the energy sector. The model may be used to examine the long-term effect of changes in the price or availability of energy on economic growth. Analysis of the short-term impact of sudden leaps in import prices or the effect of curtailed energy production on employment, inflation, and the business cycle are not model objectives.

The focus on global, long-term energy questions does not imply that short-term, national-level energy problems are not worth considering. Rather, the IIASA approach is meant to complement the numerous national studies that examine the next two decades in detail. Its long-term global features provide national and regional research groups with a means for checking their results in an international context, e.g., checking the consistency

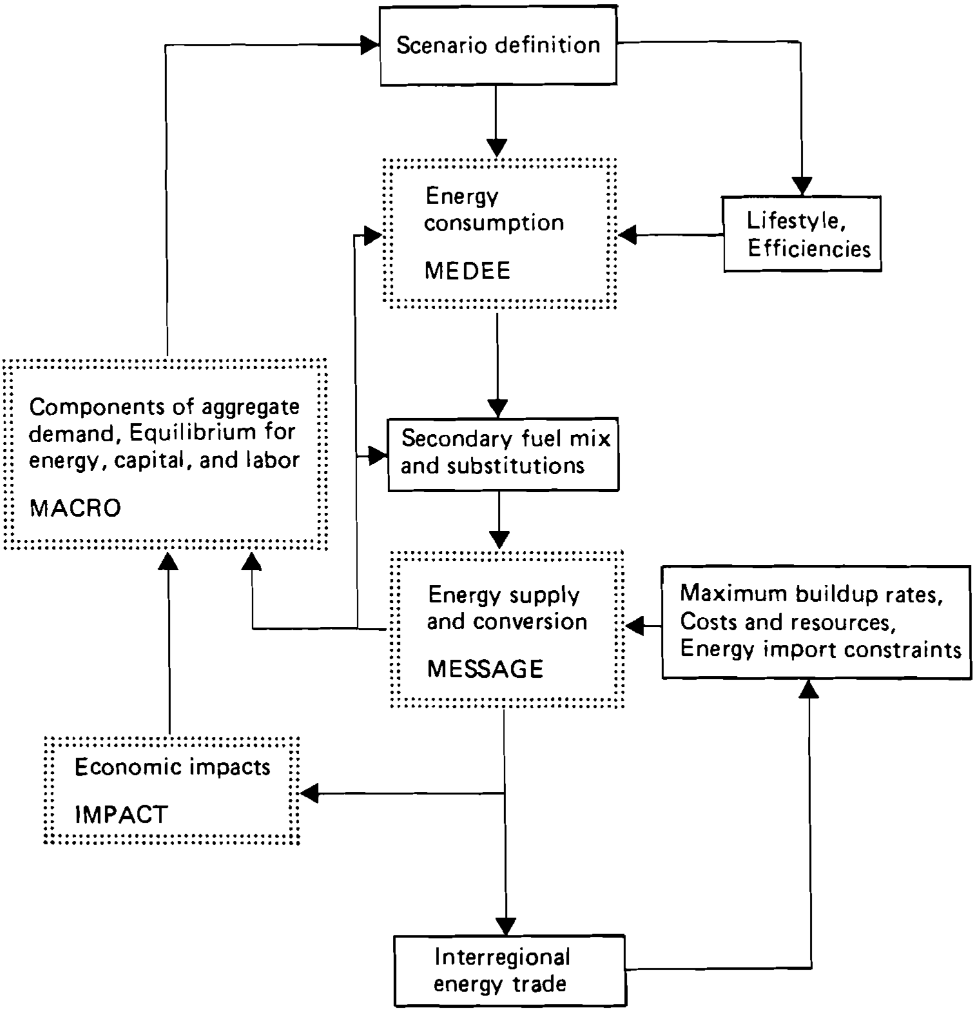

FIGURE 2 IIASA's set of energy models: a simplified representation.

of assumptions about energy trade, energy prices, or resource availability on the international energy market.

### *An Application of MACRO to the European Community*

The need for such consistency checks became clear to the Commission of the European Communities' Directorate-General for Research, Science and Education (DG XII), when it began to examine the future energy supply options available to EC member nations. DG XII had developed, in collaboration with national research institutions, detailed energy demand and supply strategies for each of its member countries. As one might expect, the economic growth targets of each national economy – oriented to past experience and guided by a politically desirable evolution over time – resulted in ever-increasing demands for energy (CEC 1979). Aggregation of the energy import quantities associated with each national economy led inescapably to the question whether the energy import requirements are feasible in a global context.

Because the global approach of IIASA's Energy Systems Program was developed to examine just this type of question, DG XII requested that IIASA perform a case study of the EC region, focusing on competition for energy sources on the world energy market, oil import ceilings, and the impact of energy availability and prices on the economic growth of EC member nations.

The first step of the case study was to locate the EC region within the IIASA classification of world regions. The EC member countries[1] were identified as a part of Region III (Western Europe, Japan, Australia, New Zealand, and South Africa). It was then necessary to disaggregate Region III into "EC" and "non-EC" components, in order to make realistic assumptions about economic growth rates, aggregate energy resource availability, lifestyles, and other factors. If this had not been done, for instance, Australian coal and uranium would have been considered domestic energy resources for the EC region.

To perform this disaggregation, the models shown in Figure 2 had to be calibrated to the EC level. This was especially important in the case of the MACRO macroeconomic module; for some models it is sufficient to modify initial conditions, constraints, and input parameters. In the case of the macroeconomic module, however, one must redesign the model's internal structure, reestimate the parameters, and revalidate the model for any new application. As will be shown in subsequent sections, each of these steps was carried out in applying MACRO to the EC region.

### *The Objectives of MACRO*

The need for a long-term macroeconomic model to examine the EC economy led to the development of the version of MACRO described in this report. Although the model is contemplated for use in energy analysis, it is not explicitly energy oriented. Rather, it is a basic macroeconomic model suitable for analyzing any economic sector characterized by long-term structural change. Briefly stated, MACRO has the following features: it is applicable for long-term analyses (up to 50 years); it is able to distinguish between a specific sector and the "rest of the economy" on an aggregate level; it is capable of capturing crucial problems arising between the sector of interest and the "rest of the economy"; it can test imposed normative structural changes; and it provides a "homomorphic picture" of the existing economic infrastructure.[2] An effort was also made to assure that MACRO is transparent to noneconomists.

The following sections of this report describe in detail the role of MACRO within the IIASA set of energy models, the model's mathematical structure, tests of model validity, and the results of four long-term applications of MACRO to the European Community. The report ends with a brief statement of model weaknesses and strengths.

## 2 MACRO'S POSITION WITHIN THE IIASA SET OF ENERGY MODELS

The conceptualization of any mathematical model depends on the larger setting in which it is to be used. Thus, MACRO is highly influenced by the other models with which it interacts in the IIASA set of energy models. A brief summary of each component of the model set, shown schematically in Figure 2, is given below.

### *Scenario Definition*

Experience in mathematical modeling has shown the expedience of summarizing all assumptions and exogenous inputs used in model runs in the form of scenarios. Consequently, the modeling activity in the IIASA energy study begins with the definition of scenarios in terms of such variables as demographic development, evolution of productivity and technology, lifestyle development, and economic growth. Such scenarios are not predictions, but rather conceptualizations of the future status of the world, a nation, or a region. Thus, they delimit *a priori* the range of conceivable trajectories over a planning period. The scenario definition stage is shown at the top of Figure 2.

### *The MEDEE Energy Demand Model*

Scenario projections of demographic and economic development, lifestyle, and other variables affecting energy consumption in a given region are basic inputs for the MEDEE[3] energy demand model (Lapillonne 1978). MEDEE considers energy-consuming activities in three economic sectors: transportation, household and services, and industry (which in turn is disaggregated into agriculture, mining, manufacturing, and construction subsectors). Gross regional product, broken down into its components (e.g., value added by industrial sector and investment shares) over time, serves as an essential scenario parameter for MEDEE runs. Other important inputs include the market penetration rates of advanced technologies, such as solar panels or district heat, which affect the mode of final energy consumption.

Simulation and accounting subroutines within MEDEE combine parameters describing future lifestyle changes with economic indicators to calculate the useful energy demand associated with each economic sector over the next 50 years. Useful energy includes categories such as space heat, water heat, high temperature heat for industrial processes, and specific electricity in the service sector. The model then evaluates various types of final energy demand on the basis of the penetration rates of district heat, electricity, or other modes of energy consumption. Substitutable uses of energy, including electricity, solar power, or fossil fuels for heating purposes, are important in this context. The composition of substitutable final energy demand is highly dependent on relative energy supply prices and is therefore subject to change as prices of alternative energy sources evolve differently.

The disaggregation of the final demand for fossil fuels among solid, liquid, and gaseous fuels is required as input to the energy supply model MESSAGE[4] (Agnew et al. 1979). This step is carried out exogenously to the IIASA set of energy models, as indicated by the box labeled "Secondary fuel mix and substitution" in Figure 2.

### *The MESSAGE Energy Supply and Conversion Model*

MESSAGE is a dynamic linear programming model used to calculate cost-optimal energy supply strategies on the basis of MEDEE's energy demand results. In the model, selection among various primary energy sources is tightly constrained by energy resource availability, technological development, and the buildup rates of new energy production capacities (such as power stations, mines, and conversion plants). Resource constraints are represented by the availability of oil, gas, coal, and uranium in each region, further classified in ascending order of their extraction costs. In the case of the EC region, which is highly dependent on energy imports, resource constraints include availability of non-domestic energy sources, again split into different cost categories, or energy import restrictions.

Technological development is handled through specification of the points in time when new and advanced energy production and/or conversion technologies are introduced on a large scale. The buildup rates used in the model reflect the inherent lead times needed for structural change in the energy sector.

Briefly stated, MESSAGE provides the time trajectories of different primary fuels along the chain of conversion processes that lead to the various types of secondary energy demands derived from the final energy demands calculated by MEDEE. With the help of shadow prices, one can also use the model to calculate marginal costs for the supply of secondary energy, and in this way derive supply cost-prices for various energy sources. Thus, MESSAGE provides the cost-optimal mix of primary fuels to supply the energy demand of a given scenario, the required production and conversion capacities, energy import needs, and energy supply prices.

### *The IMPACT Model*

MESSAGE outputs (fuel production and conversion capacity requirements) are fed into IMPACT[5], a dynamic input–output model with special emphasis on investment needs in the energy sector (Kononov and Por 1979). The model calculates direct and indirect capital requirements for a given energy strategy. (In this context, the term "indirect" means capacity and corresponding investment needs associated with energy-related industrial branches.) In addition, IMPACT accounts for materials, equipment and services, facilities, and manpower required by the energy sector and its related branches.

### *MACRO's Role in the Model Loop*

MACRO's interactions and feedbacks with the other models in the IIASA model loop are shown in detail in Figure 3. MESSAGE provides time series of primary and secondary energy supply, energy imports, and energy supply costs. IMPACT supplies MACRO with the direct investment and manpower requirements of the energy sector.[6] For consistency, the scenario assumptions (indicated in the upper right-hand side of Figure 3) used in MEDEE runs must be identical with those used in MACRO runs. These assumptions concern demographic trends, productivity, changes in lifestyle, and number of working hours per week, to mention a few.

Given these inputs, MACRO then evaluates the impacts of energy import requirements and capital and manpower needs on economic activity. The model may be used to examine the following types of issues:

- What are the effects of steeply increasing energy import prices, and the accompanying transfer of income to oil-importing nations, on domestic investment behavior?
- What effects do energy price increases have on consumption rates, on the cost of capital (interest rates), on the labor market, and on the trade balance?
- What energy prices are needed to induce a given level of energy conservation?

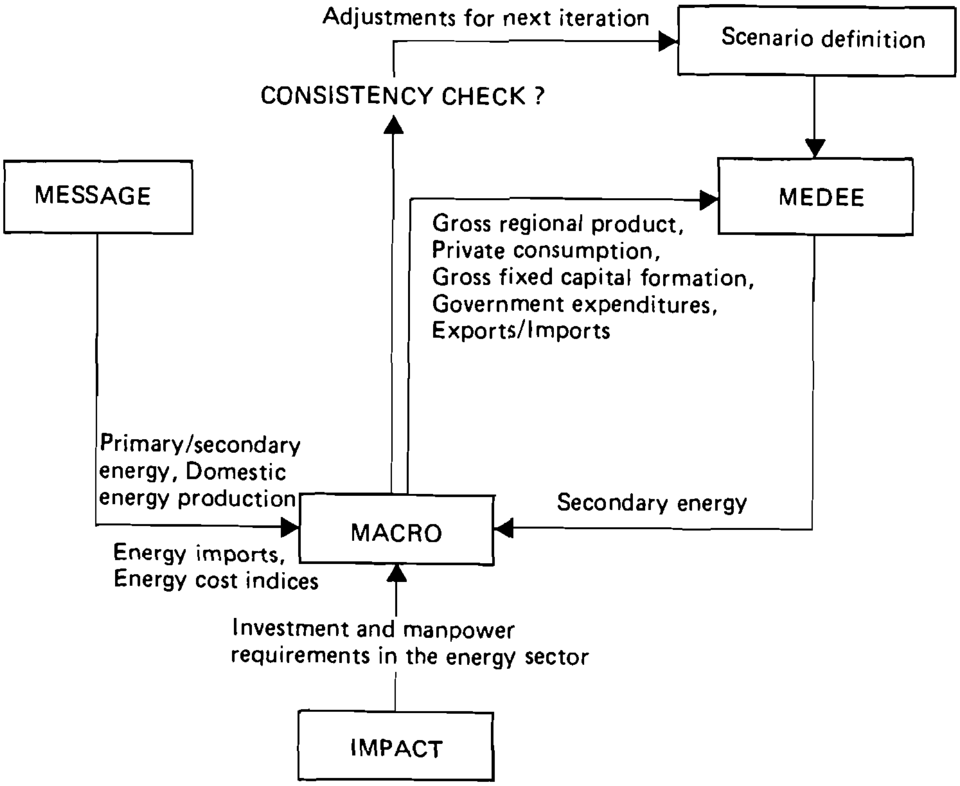

FIGURE 3 An overview of the flow of information between MACRO and other components of the IIASA set of energy models.

- Are the substitution effects of capital and labor efficient enough to permit the economy to operate with less energy and still sustain historically observed economic growth rates?
- Can sufficient capital be diverted to the energy sector in the future to create the necessary energy supply infrastructure?

Four scenarios, described in Section 8 of this report, illustrate the use of MACRO to examine such questions.

## 3 GENERAL MODEL STRUCTURE

### *MACRO as a General Equilibrium Model*

MACRO is a numerically formulated macroeconomic model constructed to reflect the economy of the European Community. As a simple, highly aggregated, two-sector model, it belongs to a group of general equilibrium models often applied in long-term macroeconomic energy modeling.

As will be described in greater detail in the following section, MACRO is built around a constant elasticity of substitution (CES) function. Following the neoclassical approach, the model focuses on supply-constrained economic activity, with special emphasis on energy as the constrained input factor. In this framework the model represents substitution processes between energy and other factors of production.

The equilibrium feature of MACRO requires an adequate representation of factor demand and supply functions. Here the model adheres to the method used by Manne (1977) and Sweeney (1979), in so far as its factor demand functions are derived from the first-order optimality condition (which implies that production factors' marginal products are identical with their market prices, under the assumption that profit-maximizing behavior prevails in the production process). The model extends the work of Manne and Sweeney by implementing explicit factor supply functions, rather than just assuming that demand will create its own supply. In addition, the parameters of the CES production function are calculated on the basis of real time-series data, instead of being determined exogenously on the basis of judgment.

The components of final demand in MACRO are based on the definition of gross regional product. Following a quasi-Keynesian approach, they determine the aggregate levels of private consumption, government expenditures, and variations in exports and imports. The gross fixed capital formation component of final demand is derived from the equilibrium condition of a cleared capital market.

### *Use of MACRO for Long-Term Analyses*

Traditionally, econometric models have been used for short-term econometric analyses covering approximately five years into the future. They are constructed on the basis of historical cross-sectional data by economic sector or time series of macroeconomic data covering a sample period of 30 years or more. Thus the sample period used to estimate and validate functional descriptions of various economic relationships is generally long compared to the prediction period.

In the case of MACRO, however, observations from a sample period of approximately 20 years have been used to construct a model with a 50-year planning horizon, and great care had to be taken in extrapolating, far into the future, econometric functions estimated over the relatively short sample period. One reason is that the user is not able to predict accurately the many exogenous or predetermined variables that must be specified to run the model; these include demographic trends, technological development, and relative prices. Another reason is that short-term trends, inherent in functions estimated on the basis of historical data, may not prevail in the future.

To overcome these difficulties, MACRO was constructed on the basis of certain important relations and variables whose values have been observed to remain fairly stable – within a certain range – in industrialized countries over several decades (Rogner 1977). Such slowly changing variables include the capital: output ratio, investment and consumption rates, population, and labor force participation. By concentrating on these "slow" variables, short-run fluctuations of "fast" variables (such as gross regional product, private consumption, or fixed capital formation) can be avoided. In addition, the number of exogenous variables is kept to a minimum in MACRO, in order to reduce possible inaccuracies introduced by their uncertain values.

In addition to "slow" variables, MACRO contains several exogenously determined scenario parameters labeled $\eta$. These can be used to countervail the short-term trends inherent in the estimated parameters. For example, a scenario parameter can be adjusted to change the export or import share of gross regional product to reflect rapidly increasing transfer payments to oil-producing countries. Scenario parameters also provide a means for simulating the evolution of the EC's economic structure (e.g., changes in the share of fixed capital formation within the gross domestic product).

"Slow" variables, together with $\eta$s, make MACRO a useful tool for modeling both historical trends and imposed long-run normative changes, while guaranteeing consistency in a macroeconomic sense. The substitution of advanced, capital-intensive energy technologies for the present oil-based energy supply and demand infrastructure – which is conceivable and even likely – may well necessitate certain normative changes.

### *MACRO as a "Potential" Model*

MACRO is a "potential" model in the sense that it represents maximum available output of the economy under optimal utilization of all input factors. Institutional policy is thus assumed to be effective in maintaining aggregate demand under sustained full employment. Small deviations from this principle might result from drastic changes in the availability of energy on the labor market, however, and the model has also been designed to reflect such disequilibrium situations.

One should bear in mind that MACRO was not developed to predict the future. Its main service is to examine a delimited set of plausible scenarios – represented by scenario parameters and exogenous variables – for the future.

## 4 THE BASIC MACRO MODEL

MACRO represents a simple two-sector economy, consisting of an energy sector and the rest of the economy (ROE). The energy sector itself consists of an energy import subsector and a domestic energy production subsector, whose activities are determined by the energy supply model MESSAGE. Energy supply is thus exogenous to MACRO, but certainly endogenous to the integrated set of models shown in Figures 2 and 3.

MESSAGE calculates the required energy import quantity $E^{\mathrm{I}}$ and its price $p_I$ for input to MACRO. The domestic energy production sector is represented in MESSAGE by various cost functions for different types of energy production activities. The required energy import quantity $E^{\mathrm{I}}$ is equal to the difference between energy production and energy demand. Both subsectors charge against the output $Y$ of the rest of the economy. In the case of the energy import subsector, income is transferred to the energy-producing countries; in the case of the domestic energy production subsector, resources from the ROE sector are used to produce its output $E^{\mathrm{D}}$.[7]

It is important to note in this context that all energy is treated solely as an intermediate good. The portion of energy that usually satisfies final demand should be considered here as an intermediate means for achieving the final values of comfort, mobility, or sophistication. The output $Y$ of the ROE sector may be either a final or an intermediate good.

The ROE sector requires as inputs a quantity of capital services $K$, a quantity of labor services $L$, and a quantity of secondary energy $E$. The output $Y$ of the ROE sector is an aggregate quantity of goods and services that depend on the inputs $K$, $L$, and $E$. The relationship between $K$, $L$, and $E$ can be represented by an aggregate production function of the economy $F(K,L,E)$.

If one assumes that production is based on profit maximization under perfect competition on all markets (capital, labor, and energy), then producers take the price of inputs as given and production levels are adjusted to the point where the marginal products of capital, labor, and energy are equal to their respective input prices. In a competitive economy this means, for instance, that the price of domestically produced energy is equal to the marginal costs of producing energy, which, in turn, is equal to the energy import price at an equilibrium stage. Labor and capital markets (supply and demand) require similar marginal conditions for market clearance. The factors capital and labor are rewarded by their marginal products, which equal the cost of capital $p_K$ and the wage rate $p_L$, respectively.

## 4.1 Basic Relations within MACRO

MACRO is a very compact model, consisting of the ten basic relations presented below. A similar approach can be found in Manne (1977) and Sweeney (1979).

The gross regional product *GRP* is given by the sum of the output $Y$ $[Y = F(K,L,E)]$ of the ROE sector [corrected for the charges against the economy of both the energy import sector $E^{\mathrm{I}}$ with its price $p_I$ and the domestic energy production sector with its aggregate cost function $G(E^{\mathrm{D}})$] and the value added that is generated by the energy sector $V^{\mathrm{E}}$:

$$GRP = F(K,L,E) - p_I E^{\mathrm{I}} - G(E^{\mathrm{D}}) + V^{\mathrm{E}} \tag{4.1}$$

$$E = (E^{\mathrm{I}} + E^{\mathrm{D}})cf \tag{4.1a}$$

$$Y = F(K,L,E) \tag{4.1b}$$

At this point in the discussion the contribution of the energy sector to *GRP* is set aside, and the profit-maximization behavior in the production process is applied only to the ROE sector. This appears reasonable, since one of the main purposes of applying MACRO is to analyze the impacts of various energy supply strategies on the evolution of the ROE sector, which in the past has produced more than 95% of total *GRP*. It is further assumed that the energy sector's contribution of value added to *GRP* is not necessarily based on the optimal allocation of capital and labor; such a case occurs when a reduction of dependence on energy imports becomes politically desirable.

It should be noted that the quantity $E$ is secondary energy, while $E^{\mathrm{I}}$ and $E^{\mathrm{D}}$ represent primary energy. The parameter $cf$ in eqn. (4.1a) is the conversion factor between primary and secondary energy. The essential assumption in eqn. (4.1) is the existence of the aggregate production function given in eqn. (4.1b).

For further analysis it is convenient to aggregate the two energy subsectors into one sector. The price of secondary energy $p_E(E)$ is then a weighted average of the price of imported and domestically produced primary energy, taking into account the costs of converting primary energy to secondary energy as provided by MESSAGE. Equation (4.1) then takes the form

$$GRP = F(K,L,E) - p_E(E)E + V^{\mathrm{E}} \tag{4.1c}$$

It is assumed here that the price of energy $p_E$ is a function of the amount of secondary energy required by the economy. This reflects the fact that available primary energy import volumes from energy-exporting countries depend implicitly on their profit function $\pi_{\mathrm{O}}$:

$$\max \pi_{\mathrm{O}} = p_I(E)E^{\mathrm{I}} - c(E)E^{\mathrm{I}}$$

where the term $c(E)$ implicitly represents their assumed energy extraction cost function.

The explicit profit-maximization assumption for a competitive economy (in this model the ROE sector) may be expressed as

$$\max \pi = F(K,L,E) - p_E(E)E - p_L L - p_K K \tag{4.2}$$

The aggregate production function $F(K,L,E)$ is subject to a number of specific restrictions (see Allen 1967). The production function is continuous and twice differentiable; the partial derivatives $\partial F/\partial x_i = F_i$ $(x_i = K,L,E)$ are interpreted as the marginal products $F_K, F_L$, and $F_E$, respectively, and the marginal productivity of the inputs $K,L$, and $E$ are $\partial F/\partial x_i = F_i > 0$, with $F_i$ decreasing as the input of $x_i$ increases. This implies that $\partial^2 F/\partial x_i^2 < 0$ or that there is a decreasing marginal rate of substitution. The marginal rate of substitution $R$ is derived from the production function [eqn. (4.1b)] by taking the total differentials – assuming a constant product isoquant $[Y = F(K,L,E) = \text{constant}]$. Any variation along such an isoquant, such as would be caused by a change in the structure of relative prices of input factors, results in

$$\mathrm{d}Y = \mathrm{d}F(K,L,E) = F_K \mathrm{d}K + F_L \mathrm{d}L + F_E \mathrm{d}E = 0$$

For a constant output $Y$ and assuming that $K$ is substituted for $L$ and that $\mathrm{d}E = 0$, the marginal rate of substitution $R$ from any given $K:L$ ratio is

$$R(K,L) = -\mathrm{d}K/\mathrm{d}L = F_L/F_K \tag{4.3}$$

which is the absolute value of the slope of the isoquant at point $(K,L)$ (see Figure 4).

Further restrictions concern the "constant returns to scale" feature and the requirement that the production function be linear and homogenous. If a production function is subject to these restrictions, then the necessary conditions for $\pi$ in eqn. (4.2) to be a maximum are $\partial \pi/\partial x_i = F_i - p_i = 0$. It follows from the assumption that production is adjusted to the point where the input factors are rewarded their marginal products (which are equal to their corresponding real market prices) that $F_i = p_i$. Therefore, according to eqn. (4.2)

$$\partial \pi/\partial E = F_E - \partial p_E(E)E/\partial E - p_E(E) = 0 \tag{4.4}$$

$$F_E - p_E(E)[1 + \partial p_E(E)E/\partial E p_E(E)] = 0 \tag{4.4a}$$

The first-order optimality condition of the profit-maximization assumption pertaining to energy contains an energy price elasticity term $\epsilon_1$; this is due to the assumed dependence

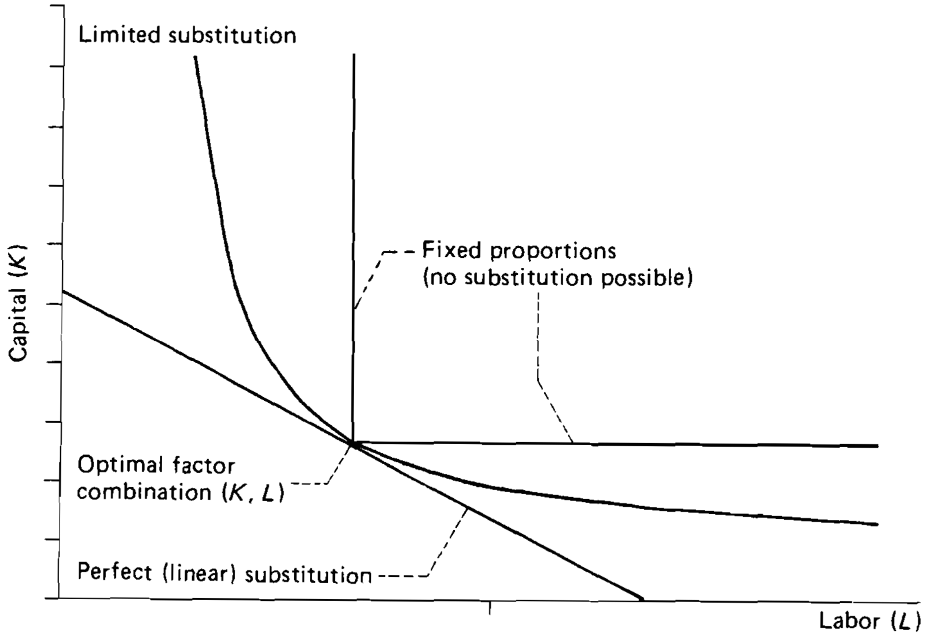

FIGURE 4 Idealized factor substitution curves. Each curve (isoquant) defines combinations of capital $K$ and labor $L$ that produce constant output.

of the domestic energy price on the absolute amount of energy demand, as well as on the export price pattern of energy-exporting countries.

$$F_E - p_E(E)(1 + \epsilon_1) = 0 \tag{4.4b}$$

$$\partial \pi / \partial L = F_L - p_L = 0 \tag{4.5}$$

$$\partial \pi / \partial K = F_K - p_K = 0 \tag{4.6}$$

Renormalization of eqns. (4.4)–(4.6) for $K$,$L$, and $E$ results in input demand functions for capital, labor, and secondary energy, respectively.

In an equilibrium stage of an economy, the demand for input factors has to be met by supply. In the IIASA model loop, supply of secondary energy $E^S$ is an output of the MEDEE/MESSAGE models. Labor supply $L^S$ essentially depends on the demography $POP$ of a region (overall population, age distribution, and labor force participation) and the real wage rate or price of labor:

$$L^S = g(POP, p_L) \tag{4.7}$$

The supply of capital stock $K^S$ for the present period equals the capital stock of the previous period plus the gross fixed capital formation *INV*, corrected for consumption of fixed capital *DEP*:

$$K^S = K(-1)^S + INV - DEP \tag{4.8a}$$

Capital supply or gross fixed capital formation is a function of gross regional product *GRP*, the cost of capital $p_K$, and the real trade balance *TB*:

$$INV = f(GRP, p_K, TB) \tag{4.8b}$$

In industrialized economies like the EC, the investment or savings ratio $s = INV/GRP$ has remained remarkably stable for decades. The generally observed fluctuations of $s$ due to business cycles can thus be neglected, using a long-term perspective. It is quite a common concept in economics to use *GRP* and the cost of capital (interest rate plus the rate of depreciation) in the functional determination of the share of *GRP* that adds to the existing capital stock (after correction for depreciation). In addition to *GRP* and $p_K$, the term *TB* (the real trade balance) has been introduced into eqn. (4.8b), since over the long term steeply increasing energy import prices will charge against *GRP* by increasing transfers of economic resources from the EC region to the energy-exporting countries (also see Klein et al. 1979).

For the past two decades, the nominal trade of the EC region has been almost balanced (or slightly positive); thus

$$p_X X - p_M M = 0 \tag{4.9}$$

where $X$ represents exports, $M$ represents imports and $p_X$ and $p_M$ are their corresponding prices. If one divides the nominal trade balance by the export price $p_X$ and labels the difference *TB*, one obtains:

$$X - Mp_M/p_X = TB \tag{4.9b}$$

This relation measures exports $X$ less the cost of imports $Mp_M$, calculated in terms of export prices.

The oil-pricing policy of energy-exporting countries during the post-1973 period had a slightly unfavorable effect on the magnitude of *TB* for the EC economy. As long as the ratio of import prices to export prices $(p_M/p_X)$, i.e., the reciprocal of the terms of trade, is greater than unity, the value of *TB* is negative. A negative trade balance indicates a drain of resources to energy-exporting countries caused by unfavorable terms of trade (a direct consequence of rising energy import prices).

It is reasonable to assume that real losses of income will negatively affect the propensity to save within the EC economy; this in turn will have a feedback effect on overall economic activity, by slowing down the *GRP* growth rates. This may be considered a "quasi"-negative multiplier effect.

With the help of the above equations, the model can now clear capital, labor, and energy markets by adjusting $p_K$, $p_L$, and $p_E$ to the equilibrium levels of $K$, $L$, and $E$. After such an iterative adjustment process, the total change in *GRP* can be calculated analytically by taking the total differentials of eqn. (4.1), using eqns. (4.4)–(4.6):

$$\Delta GRP = -E^{\mathrm{I}}\Delta p_I - E^{\mathrm{D}}\partial G(E^{\mathrm{D}}) + p_L\Delta L + p_K\Delta K \tag{4.10}$$

In eqn. (4.10) the changes in *GRP* are expressed as the sum of weighted changes in imported energy and its import price, in domestically produced energy, in the domestic energy cost function $\partial G(E^{\mathrm{D}})$ characterizing the domestic energy production sector, as well as in capital and labor deployment.

## 4.2 The Aggregate Production Function

The aggregate production function $Y = F(K,L,E)$, outlined above, must now be specified in more detail. This function uses the input factors, capital $K$, labor $L$, and energy $E$, to produce gross output $Y$. Gross output in such a configuration includes the output of energy as an intermediate input factor, in addition to the real value added that is contributed by capital and labor.[8] Any change in the relative price structure of capital, labor, or energy leads to the substitution of input factors in the production of output $Y$, as well as to changes in real value added or *GRP*. This double effect is a well-known problem in identifying real value added, since the output of any commodity or economic sector is determined by the inputs of a number of other commodities or sectors. Some of these inputs are the primary inputs of capital and labor, while others are intermediate goods like materials or energy, as in the case of MACRO.

Statistical bureaus usually begin constructing national accounts by calculating the money or nominal value added that constitutes the difference between the nominal values of gross output and intermediate inputs. Real value added is then derived by deflating the nominal flows and calculating the difference between the resulting real quantities. This "double deflating" method unavoidably incorporates a wide range of inconsistencies, due to variations in absolute and relative prices across time and space.

Arrow (1974) suggests an alternative approach to measuring real value added; he argues that the "most natural meaning" of this quantity arises from the wish of economists to estimate production functions. It is the need to attribute a special role to the primary input factors of capital and labor and to construct an aggregate term for these factors that calls for measuring real value added. But such an aggregation of capital and labor can only be justified as long as their use in production is separable from that of other inputs, i.e., energy. If one assumes separability of primary input factors and energy, the measurement of real value added can only be pursued if the production function $Y = F(K,L,E)$ takes on the special nested form

$$Y = \Phi[E, V(K,L)] \tag{4.11}$$

where real value added $V$ of the ROE sector is a function of only capital and labor. Leontief (1947) noted that the condition for separability is given if the marginal rate of substitution between capital and labor in the production of output $Y$ is independent of energy. In practice, this means that capital and labor produce the intermediate good $V$, which, combined with energy, then produces gross output $Y$.

This approach has one important inherent consequence: energy does not appear in the production function for real value added. Therefore, the real value added that is associated with the ROE sector only responds to changes in energy inputs if such changes affect the level of capital and labor inputs. It is essential to keep this consequence in mind, and to use factor supply and/or demand functions to capture the feedback between changes in energy costs and real value added.

## 4.3 The CES Production Function

A production function with the characteristics of eqn. (4.11) belongs to the class of production functions with constant elasticity of substitution (CES functions) proposed by Arrow et al. (1961). The authors based their theoretical work on the empirical observation that, within a given industry, value added per unit of labor varies by country, with the wage rate accounting for profit-maximizing responses of producers to given factor prices. Application of the linear relationship between the logarithms of output $Q$, or value added per unit of labor $Q/L$, and the wage rate $w$ produced a good fit to the empirical data[9].

$$\ln(Q/L) = \ln a + \sigma \ln w \tag{4.12}$$

where $a$ and $\sigma$ are parameters that will be discussed below.

Given the existence of this relationship between wages and output per unit of labor, Arrow et al. asked what sort of production function could be used to rationalize it. The form of the production function given in eqn. (4.12a) is based on the assumption that the aggregate producer technology can be represented by a continuous, quasi-concave, and nondecreasing function of the type

$$Q = f(K,L) \tag{4.12a}$$

or

$$Q/L = h(K/L,\, 1) \tag{4.12b}$$

Assuming the identity of factor prices of capital and labor with their marginal products (or competitive factor markets), it is convenient to replace the wage rate $w$ in eqn. (4.12) with the first-order optimality condition for labor in eqn. (4.12b). Arrow and his colleagues used this procedure to arrive at a differential expression of the following kind:

$$\ln\left(\frac{Q}{L}\right) = \ln a + \sigma \ln\left[\frac{Q}{L} - \frac{K}{L}\frac{\partial(Q/L)}{\partial(K/L)}\right] \tag{4.13}$$

Taking the antilogs and solving for $\partial(Q/L)[\partial(K/L)]^{-1}$, one may substitute the term $\beta$ for $1/(\sigma - 1)$. Further rearrangements and transformations lead to the following CES production function, which is homogenous of degree one:

$$Q = \gamma\,[\delta K^{-\beta} + (1-\delta)L^{-\beta}]^{-1/\beta} \tag{4.14}$$

where

$$\beta = (1 - \sigma)/\sigma \quad \text{or} \quad \sigma = 1/(1 + \beta) \tag{4.15}$$

In eqn. (4.14) $\delta$ fixes the distribution between input factors, while $\beta$ represents the substitution parameter. The elasticity of substitution $\sigma$, derived from $\beta$ as shown in eqn. (4.15), is defined as follows [see also eqn. (4.12)]:

$$\sigma = \partial \ln(K/L)/\partial \ln R$$

$R$ is defined as in eqn. (4.3):

$$R(K,L) = -\mathrm{d}K/\mathrm{d}L = F_L/F_K \tag{4.16}$$

In eqn. (4.14) $\gamma$ changes output $Q$ for any given set of inputs $K$ and $L$ in the same direction and proportionally. In this context, $\gamma$ has been referred to as the neutral efficiency parameter. Although any technical progress causes a shift in the production function, the marginal rate of substitution for each prevailing $K$:$L$ ratio remains unaffected as long as a change in efficiency is solely reflected by $\gamma$.

$\beta$ is the substitution parameter. Its connection to the elasticity of substitution was discussed above. $\delta$ is the so-called distribution parameter. For any given value of $\sigma$, $\delta$ determines the functional distribution between the input factors. Taking the additional required characteristics of a production function into consideration (i.e., it should have positive marginal products for all inputs and should be subject to diminishing returns in varying proportions), one can easily derive the permissible ranges of the parameters in eqn. (4.14). It is obvious that output $Q$ will be positive if $\gamma > 0$ and as long as $0 < \delta < 1$ (positive values of the input factors being a prerequisite). The substitution parameter $\beta$ ranges from $-1 < \beta < \infty$ ($\beta = 0$ being excluded), allowing $\sigma$ to range from $0 < \sigma < \infty$ ($\sigma \neq 1$). The value $-1$ for $\beta$ implies an infinite elasticity of substitution; the value 0 leads to a Cobb–Douglas function (see Arrow et al. 1961).

In general, one assumes production isoquants to be downward sloping and convex to the origin, with an asymptotic approach to the $L$ and $K$ axis. Inclusion of this assumption in the application of a CES production function then dictates that $\sigma$ is in the range from $0 < \sigma < 1$ or that $\beta > 0$.

## 4.4 The CES Production Function in MACRO

MACRO contains a CES production function encompassing secondary energy $E$, capital $K$, and labor $L$ in the nested image shown earlier in eqn. (4.11):

$$Y = \Phi[E, V(K,L)]$$

Explicitly, the production function takes the following form:

$$Y = \gamma[\delta E^{-\beta} + (1 - \delta) V(K,L)^{-\beta}]^{-1/\beta} \tag{4.17}$$

The ROE sector's value added $V$ itself is determined by a Cobb–Douglas production function with the unit elasticity of substitution between its factor inputs, capital and labor. In eqn. (4.18) $1 - \alpha$ represents the share of payments to capital and $\alpha$ is the share of payments to labor[10]:

$$Y_{\$70} = \gamma[aE^{-\beta} + b(\theta K_{\$70}^{1-\alpha} L^{\alpha})^{-\beta}]^{-1/\beta} \tag{4.18}$$

In eqn. (4.18) the distribution parameter $\delta$ has been replaced by parameters $a$ and $b$ due to the difficulty of avoiding dimensional errors in the measurement of the variables involved. Allen suggests that the individual magnitudes of parameters $a$ and $b$ do not necessarily need to add to unity, since they are determined by the unit chosen for measuring gross output $Y$[11].

The parameter $\alpha$ was derived from the product exhaustion requirement, i.e., the identity between $GRP$ and aggregate compensation of labor plus payments to capital.

$$GRP_{\$70} = p_L L + p_K K_{\$70} \tag{4.19}$$

or

$$\alpha = p_L L / GRP_{\$70} \tag{4.20}$$

Available data for the EC region suggest a value of 0.661 for $\alpha$.

The term $\theta$ in eqn. (4.18) represents the neutral efficiency parameter of the Cobb–Douglas production function. This efficiency parameter must be clearly distinguished from $\gamma$; the latter reflects shifts, due to technical progress, in producing output $Y$, with secondary energy $E$ and value added $V$ as input factors.

The parameter $\beta$ and the distribution ratio $a/b$ in eqn. (4.18) were estimated using the neutrality condition of the efficiency term $\gamma$ in eqn. (4.14). Taking the first derivatives of eqn. (4.17) with respect to energy $E$ and value added $V$, and adopting the ratio $F_E/F_V$ (equivalent to the price of energy over the price of value added), one arrives at the following expression:

$$F_E/F_V = p_E/p_V = (a/b)(V/E)^{\beta+1} \tag{4.21}$$

If one rearranges eqn. (4.21) and takes the logarithms, one obtains

$$\ln(p_E E/p_V V) = \ln(a/b) + \beta \ln(V/E) \tag{4.22}$$

This form is easily estimated using ordinary least-squares techniques (OLS) (Johnston 1972). The estimates of the parameters $\beta$ and $\delta$ vary considerably for different sample periods, due to the greater weight of the post-1973 period relative to the total sample period. The best statistical fit, although by no means satisfactory, is obtained for the time spans of equal length before and after the disruption of the energy system in 1973/1974, i.e., for the period 1970–1978:

$$\ln(p_E E/p_V V) = -2.547200 - 1.824001 \ln(V/E) \qquad (4.23)$$
$$(-6.691) \quad (-20.764)$$
$$R^2 = 0.8455, \ se = 0.0588, \ d = 1.972$$

From the values in eqn. (4.16) it follows that $\sigma = 0.3541$, $a = 0.0723$, and $b = 0.8877$.

Allen (1967) has provided another approach to estimating the elasticity of substitution; here $\sigma$ is estimated independently of the distribution parameter $\delta$ ($a$ and $b$, respectively):

$$\ln\left(\frac{E_1/V_1}{E_2/V_2}\right) = \sigma \ln\left[\frac{(p_V/p_E)_1}{(p_V/p_E)_2}\right] \qquad (4.24)$$

Given values for $E/V$ and $p_V/p_E$ at two points in time on the production function, one can derive estimates for $\sigma$. Application of the 1967 and 1978 values yields $\sigma = 0.388286$, $a = 0.067$, and $b = 0.897$. Values of $\sigma$ for other sample periods range from 0.31 to 0.40, i.e., for the period 1970–1978 $\sigma = 0.3571$, and for the period 1970–1976 $\sigma = 0.3215$.

The difference in the values for the elasticity of substitution between the period 1970–1976 and the period 1970–1978 is mainly explained by the slowdown in overall economic activity within the EC region. The average real growth rate dropped from 3.2% per year (1970–1976) to 2.6% per year (1976–1978). Underutilization of existing capital stock and the tendency to curtail or to stop production in business sectors with low profit margins caused secondary energy use per unit of value added, i.e., energy intensity, to drop below historically observed values. In 1970 energy intensity was $1.418 \times 10^{-3}$ tce/\$, while in 1978 it was $1.235 \times 10^{-3}$ tce/\$.

Economic theory suggests that elasticities are higher in the long run than in the short run, due both to the inability of the infrastructure to adjust immediately to changing prices and to the hope that such changes will only be temporary. It is questionable whether a value of $\sigma$ at the 0.4 level can be achieved on a permanent basis, since the reduction of economic growth rather than higher energy prices has been its dominant determinant. The devaluation of the US dollar has kept the deflated energy price for Europe at its 1976 level. If the economy recovers from its present slowdown in activity, energy intensity will rise and the elasticity of substitution will drop again.

The values produced using Allen's estimation procedure, i.e., 0.388 for $\sigma$, 0.067 for $a$, and 0.897 for $b$, are adopted as reference values in MACRO. Other values for $\sigma$, such as 0.25 or 0.40, which span the range of $\sigma$ as calculated by various other estimation procedures, are employed in the model for further analyses.

Continuing our discussion of the derivation of parameters, the productivity term $\gamma$ is estimated from the following relation:

$$\ln(Y_{\$70}/Y^*_{\$70}) = \ln \gamma + rTIME \qquad (4.25)$$

The OLS estimation process then yields:

$$\ln(Y_{\$70}/Y^*_{\$70}) = -0.06774 + 0.01046\,TIME \qquad (4.26)$$
$$\qquad\qquad(5.26) \qquad (10.08)$$

$$R^2 = 0.9096, se = 0.0108, d = 0.988$$

where

$$Y^*_{\$70} = [aE^{-\beta} + b(\theta K^{1-\alpha}_{\$70}L^{\alpha})^{-\beta}]^{-1/\beta} \qquad (4.27)$$

Now it is possible to present the fully estimated production fucntion

$$Y_{\$70} = \gamma\,[aE^{-\beta} + b(\theta K^{1-\alpha}_{\$70}L^{\alpha})^{-\beta}]^{-1/\beta} \qquad (4.28)$$

with the following parameter values:

$\gamma$ = 0.9345 exp (0.01046*TIME*)
$a$ = 0.067083
$b$ = 0.897028
$\beta$ = 1.5754223
$\alpha$ = 0.660561
$\theta$ = 0.85710 exp (0.029519*TIME*)

The fit of the estimated CES production function to empirical data for the sample period is shown in Figure 5.

The lack of sufficient observations on the substitution of energy and value added, as well as the relatively small share of energy inputs to total output (in monetary terms), lead to questionable estimates of the elasticity of substitution. Hogan and Manne (1977) suggest that if the assumption of the approximate independence of output $Y$ from energy $E$ holds, then *the long-run price elasticity of energy demand and the long-run elasticity of substitution are virtually identical.*

Nordhaus (1975) and the Federal Energy Administration (1976) have studied long-run energy demand elasticities. Their findings indicate a range of 0.2–0.6 for the long-run demand elasticity, which corresponds to the elasticities estimated for the EC.

## 5 THE COMPREHENSIVE MACRO MODEL

### 5.1 Equilibrium Demand for Capital, Labor, and Energy

The explicit demand equations in MACRO for capital $K$, labor $L$, and energy $E$ – the input factors of the aggregate production sector – have been adopted as outlined above in the general description of the basic model [see eqns. (4.4)–(4.6) in Section 4]. Renormalization of the first-order derivatives of $K$, $L$, and $E$ of the aggregate CES production function [eqn. (4.28)] permits derivation of the factor demand equations for the ROE sector.

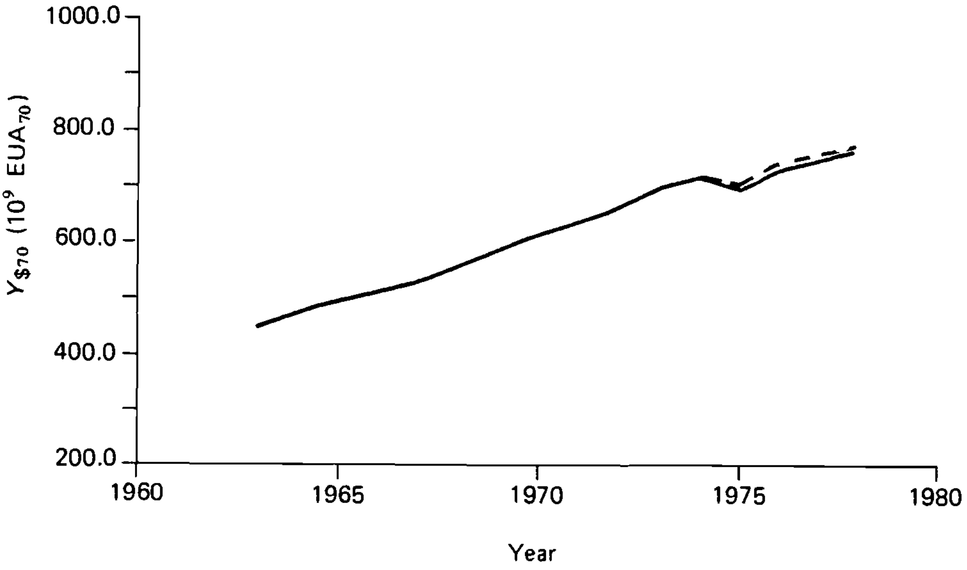

FIGURE 5 Goodness of fit of gross output $Y_{\$_{70}}$: - - - - , estimated values; ——— , actual data for EC region, 1964–1978.

When one adds the requirements for capital $K^{\mathrm{E}}$, labor $MH^{\mathrm{E}}$, and secondary energy $E^{\mathrm{E}}$ of the energy sector, as calculated by IMPACT and MESSAGE/MEDEE, to the endogenously determined factor demand of the ROE sector, one obtains total demand for the factors of production.

Derived demand for secondary energy in ROE:

$$E^{\mathrm{D,R}} = [p_E(1+\epsilon_1)\gamma^{\beta}a^{-1}]^{-1/(\beta+1)}Y_{\$70} \qquad (5.1)$$

Total demand for secondary energy:

$$E^{\mathrm{D}} = E^{\mathrm{D,R}} + E^{\mathrm{E}} \qquad (5.1a)$$

Derived demand for capital in ROE:

$$K^{\mathrm{D,R}}_{\$70} = (1-\alpha)\gamma^{-\beta}bV^{-\beta}_{\$70}\,Y^{\beta+1}_{\$70}\,p_K^{-1} \qquad (5.2)$$

Total demand for capital:

$$K^{\mathrm{D}}_{\$70} = K^{\mathrm{D,R}}_{\$70} + K^{\mathrm{E}}_{\$_{70}} \qquad (5.2a)$$

Derived demand for labor (expressed in total manhours[12]) in ROE:

$$MH^{\mathrm{R,D}} = \alpha\gamma^{-\beta} b V_{\$70}^{-\beta} Y_{\$70}^{\beta+1} p_L^{-1} \tag{5.3}$$

Total demand for manhours:

$$MH = MH^{\mathrm{R,D}} + MH^{\mathrm{E}} \tag{5.3a}$$

## 5.2 Equilibrium Supply of Capital, Labor, and Energy

Having obtained the total demand for capital, labor, and secondary energy, the next step is to define the equilibrium supply of these production factors for the entire economy. The energy-related demand (equaling supply) of these factors is determined by MESSAGE and IMPACT, and therefore has to be considered an exogenous input to MACRO. The difference between total factor supply and energy-related requirements may be taken as the supply of capital, labor, and energy of the ROE sector (also see Section 5.3).

The general form of the supply equations for capital, labor, and energy were discussed in detail in Section 4. The estimated supply equations used in the model, together with goodness of fit and autocorrelation statistics, will now be provided. The figures in parentheses under the equations show the corresponding $t$-statistic for the estimated parameter. The values for the correlation coefficients $R^2$, corrected for degrees of freedom, the Durbin–Watson statistic $d$, and the standard error of estimate $se$ are also listed below each equation.

The relatively high correlation coefficients and low standard errors indicate that most of the equations provide a good fit to the data. In assessing the goodness of fit, it should be noted that many of the Durbin–Watson statistics are too low. This implies positive autocorrelation, and, hence, upward biases in the estimates of the correlation coefficients and $t$-statistics and downward biases in the estimates of the standard errors. However, a model's usefulness is determined by the simultaneous solution of all its equations: the accuracy of the simulation as a whole over the sample period provides an indication of a model's goodness of fit.

The supply of capital is calculated via the supply of gross fixed capital formation [see eqns. (4.8a) and (4.8b)]. Application of the capital stock identity [eqn. (4.8b)] yields the desired supply of capital stock.

Gross fixed capital formation:

$$\begin{array}{llllll} INV_{\$70}^{\mathrm{S}} = & 0.176\,GRP_{\$70} & +\ 0.706\,TB & +\ 13.795\,p_K & -\ 106.150 \\ & (27.02) & (7.56) & (11.64) & (9.76) \end{array} \tag{5.4}$$

$$R^2 = 0.993,\ se = 1.118,\ d = 1.576$$

Equation (5.4) states that – other factors being constant – a unit change in gross regional product increases the supply of gross fixed capital formation $INV_{\$70}$ by 0.176 units. If the price of capital $p_K$[13] moves in either direction, $INV_{\$70}$ will change in the same direction by a factor 13.79 times the amount of the price of capital. In this sense eqn. (5.4) can be considered a savings function rather than a pure investment function.

The positive sign of the trade balance parameter ensures the intended reduction in the supply of capital in cases where unfavorable terms of trade lead to a transfer of domestic income to countries that export energy or other raw materials. Figure 6 shows the good fit of eqn. (5.4) to actual data.

The functional image of total supply of labor is given in eqn. (5.5). Here labor is measured in terms of numbers of workers. In order to compare supply of labor with demand for labor, one has to convert labor availability into manhour equivalents, as shown in eqn. (5.10).

Total labor supply:

$$L^S = -0.302(POP - POP > 65) + 7.745 p_L + 159.705 \qquad (5.5)$$
$$(-1.26) \qquad (3.06) \qquad (3.31)$$

$$R^2 = 0.923,\ se = 0.347,\ d = 1.45$$

Labor supply is a declining function of active population (roughly the population under retirement age) and is positively correlated with the real wage rate. Demographic forecasts based on age distribution studies of the EC countries predict a diminishing labor force participation rate, i.e., a decline from 44.5% in 1975 to about 30–35% 50 years from now. The negative sign of the population parameter therefore seems plausible. The wage rate parameter, however, appears somewhat high.

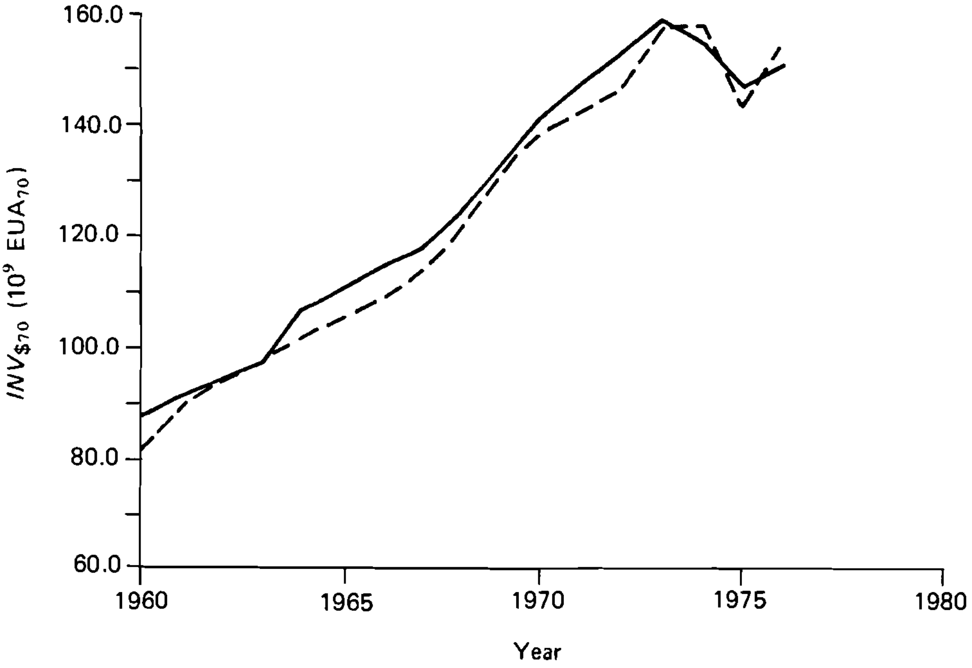

FIGURE 6 Goodness of fit of gross fixed capital formation $INV_{\$70}$: - - - -, estimated values; ——, actual data for EC region, 1960–1978.

Although the statistical fit of these aggregate data is quite satisfactory (see Figure 7), it may turn out to be necessary in the long run to manipulate the parameters of the labor supply function. Because eqn. (5.5) has been estimated on the basis of a relatively short sample period (1960–1977), it is likely that the estimated parameters reflect short-term trends characteristic of the prosperous economic development that took place during the years before 1973. Above-average productivity gains during that period allowed real wages to grow steadily, at rates higher than overall economic growth. This short-term trend undoubtedly cannot persist in the long run.

To complete our discussion of the equilibrium supply of capital, labor, and energy, secondary energy supply $E^S$ must be specified. As mentioned above, it is an output of the MEDEE/MESSAGE models.

## 5.3 Basic Identities in MACRO

### *Identities Between the Energy Sector and the Rest of the Economy*

A complete economic model requires a number of identities to guarantee consistency between aggregate demand and supply. In MACRO the breakdown of the economy into two sectors – energy and rest of the economy – must be carried one step further, i.e., some basic identities also need to be disaggregated. An example of such an identity is that gross fixed capital formation $INV_{\$70}$ equals the investment requirements of the energy sector $INV^E_{\$70}$ and those of the ROE sector $INV^R_{\$70}$.

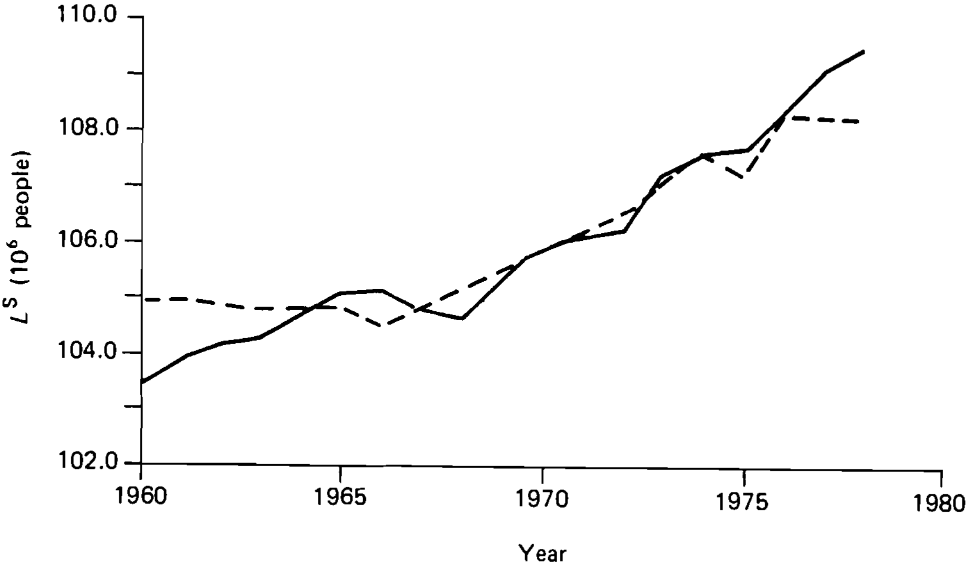

FIGURE 7 Goodness of fit of total labor supply $L^S$: - - - -, estimated values; ——, actual data for EC region, 1960–1978.

Investment in ROE:

$$INV^{\mathrm{R}}_{\$70} = INV^{\mathrm{S}}_{\$70} - INV^{\mathrm{E}}_{\$70} \tag{5.6}$$

The investment requirements of the energy sector are determined by the IMPACT model. The capital stock identity for each sector is then given by

Capital stock in ROE:

$$K^{\mathrm{R}}_{\$70} = K(-1)^{\mathrm{R}}_{\$70} - \delta^{\mathrm{R}} K(-1)^{\mathrm{R}}_{\$70} + INV^{\mathrm{R}}_{\$70} \tag{5.7}$$

Capital stock in energy sector:

$$K^{\mathrm{E}}_{\$70} = K(-1)^{\mathrm{E}}_{\$70} - \delta^{\mathrm{E}} K(-1)^{\mathrm{E}}_{\$70} + INV^{\mathrm{E}}_{\$70} \tag{5.8}$$

The $\delta$s above represent the capital depreciation factor. MACRO uses the value 4.24% for $\delta^{\mathrm{R}}$ and 3.0% for $\delta^{\mathrm{E}}$. Total capital stock is the sum of capital stock for the energy sector and capital stock for the ROE sector.

Total capital stock:

$$K_{\$70} = K^{\mathrm{R}}_{\$70} + K^{\mathrm{E}}_{\$70} \tag{5.9}$$

A similar breakdown was necessary for the labor market. Labor, as used in the production function, is measured in units of manhours. Labor force participation therefore has to be adjusted for hours worked per week *HOURS*, which is one of the important scenario variables (exogenous inputs) in MACRO. Equation (5.10) determines total labor supply for the EC economy. The manhour requirements of the energy sector $MH^{\mathrm{E}}$ for a given energy strategy are provided by IMPACT and are thus exogenous to MACRO.

Total availability of manhours:

$$MH = 52\, L^{\mathrm{S}} HOURS \tag{5.10}$$

Manhours allocated to ROE:

$$MH^{\mathrm{R}} = MH - MH^{\mathrm{E}} \tag{5.11}$$

$MH^{\mathrm{R}}$ represents the maximum manhours available to the ROE sector. This quantity is considered to be the residual of total manhour supply, an approach used as well in the determination of investment (capital) supply. This way of determining capital and manhour supply for the ROE sector is useful, because capital- and/or labor-intensive energy production technologies cause a drain of resources and primary input factors from this sector. It is thus possible to investigate the effects of capital-intensive energy supply strategies on the overall economy. The assumption underlying this approach is that the use of capital and labor is more efficient in the ROE sector than in the energy sector.

Higher capital and/or labor inputs associated with constant physical outputs (measured, for instance, in terms of kWh) certainly decrease the efficient use of these inputs.

*Gross Regional Product and Income Identities*

The basic equation in the macroeconomic model is the definition of real gross regional product $GRP_{\$70}$. $GRP_{\$70}$ is the constant value [expressed in European Units of Accounts (EUA) at 1970 prices and exchange rates] of all goods and services produced by labor in the EC member countries, and of property supplied by their residents. Three additional definitions of GRP are used in the model. First, it equals total purchases of goods and services (aggregate demand), which has the following components: personal consumption ($C_{\$70}$), gross fixed capital formation $INV_{\$70}$, government purchases of goods and services $G_{\$70}$, and net exports of goods and services $X_{\$70} - M_{\$70}$. The purpose of the demand side of MACRO is to produce a consistent set of estimates for these variables under different assumptions. The estimates should be consistent both with assumed behavioral relationships for consumers and producers and with the *GRP* and the disposable income identities.

Second, *GRP* equals the sum of payments to factors of production. Finally, the third *GRP* identity stems from the aggregate production or supply function of MACRO. Total output $Y$ must be corrected for payments to the energy sector that are not part of value added. Since output $Y_{\$70}$ represents the output of the ROE sector only, the value added produced by the energy sector $V^{\mathrm{E}}_{\$70}$ has to be added to $Y_{\$70}$.

Definitions of real GRP:

$$\begin{aligned} GRP_{\$70} &= C_{\$70} + INV_{\$70} + G_{\$70} + X_{\$70} - M_{\$70} \\ GRP_{\$70} &= p_L MH + p_K K_{\$70} \qquad (5.12) \\ GRP_{\$70} &= Y_{\$70} - p_E(E)E + V^{\mathrm{E}}_{\$70} \end{aligned}$$

Real national income $NI_{\$70}$ is the total income paid to the factors of production (labor and property). One must deduct all the nonfactor charges from $GRP_{\$70}$, i.e., indirect business taxes and surplus of government enterprises minus subsidies *TAXES* (converted into constant values by means of the general deflator $p$) and capital consumption allowances $DEP_{\$70}$. To finally secure a balance, it is also necessary to account for a statistical discrepancy. In eqn. (5.13) the term *RES* (residual) represents the statistical discrepancy and the error associated with conversion to constant monetary units, as well as the surplus of government enterprises minus subsidies.

Definition of real national income:

$$NI_{\$70} = GRP_{\$70} - DEP_{\$70} - TAXES/p - RES \qquad (5.13)$$

Disposable income $YD_{\$70}$ equals national income $NI_{\$70}$, corrected for income taxes *TAXDIR* and government transfer payments to persons *GT*. Income taxes and government transfer payments are measured in current values, and therefore it is necessary to apply the deflator $p$ to convert to constant 1970 values. To simplify the model, corporate retained earnings are included in personal disposable income.

Definition of real disposable income:

$$YD_{\$70} = NI_{\$70} - TAXDIR/p + GT/p \tag{5.14}$$

Personal consumption expenditures or private consumption $C_{\$70}$ equals national income $NI_{\$70}$ minus investments $INV_{\$70}$ plus aggregate depreciation $DEP_{\$70}$.

Definition of private consumption:

$$C_{\$70} = YD_{\$70} - INV_{\$70} + \delta^{\mathrm{R}}K(-1)^{\mathrm{R}}_{\$70} + \delta^{\mathrm{E}}K(-1)^{\mathrm{E}}_{\$70}$$

and (5.15)

$$\delta^{\mathrm{R}}K(-1)^{\mathrm{R}}_{\$70} + \delta^{\mathrm{E}}K(-1)^{\mathrm{E}}_{\$70} = DEP_{\$70}$$

An explicit consumption function [where private consumption is a distributed lagged function of disposable income and previous levels of consumption of the type $C_{\$70} = f(YD_{\$70}, \Sigma^4_{t=1} C(-1)_{\$70})$] has been omitted from MACRO for two reasons. First, lags are not appropriate for this equilibrium model. Second, the long-term application of MACRO makes it necessary to reduce econometrically estimated relations to a minimum, in order to keep the model transparent and simple, and in order to exclude short-term trends as much as possible. Furthermore, in the long run the consumption identity provides for equality of investments and savings; this is not the case when a distributed lagged function is used. As an alternative, MACRO provides a simple consumption function connecting private consumption to disposable income, where the marginal propensity to consume is 0.816.

$$\begin{aligned} C_{\$70} &= \underset{(51.637)}{0.81602}\, YD_{\$70} + \underset{(1.145)}{8.1631} \end{aligned} \tag{5.15a}$$

$$R^2 = 0.997,\ se = 0.3853,\ d = 2.145$$

*Taxes and the Government Sector*

As shown in eqn. (5.16), a renormalization of eqn. (5.12), the government sector $G_{\$70}$ is the residual of the components of aggregate demand. In conjunction with eqns. (5.18), (5.19), and (5.20), one can use this equation to examine the implications of different tax policies on aggregate demand and the budget.

Government purchases:

$$G_{\$70} = GRP_{\$70} - C_{\$70} - INV_{\$70} - X_{\$70} + M_{\$70} \tag{5.16}$$

The government's budget identity $SUR_{\$70}$ (surplus or deficit) contains tax revenues ($TAXDIR/p$ + $TAXES/p$) on the income side, and government expenditures on goods and services $G_{\$70}$ plus government transfer payments to persons $GT/p$ on the expenditure side. There is no restriction requiring a balanced budget in MACRO. The government's budget identity is a useful instrument for monitoring the effects of different energy strategies on the magnitude of budget deficits or surpluses.

Government budget:

$$SUR_{\$70} = TAXDIR/p + TAXES/p - G_{\$70} - GT/p \tag{5.17}$$

Indirect business taxes and nontax liability *TAXES* include taxes for sales, property, inspection fees, fines, royalties, and donations. The term does not include taxes on corporate income. The estimated indirect business tax function has an average tax rate of 10.6% on real GRP. $\eta_1$ is the first of four explicit scenario parameters labeled $\eta$, which are included in MACRO to allow for normative changes of parameters estimated on historically observed time series.[14] For example, in eqn. (5.18) any value of $\eta_1$ other than 1 will influence the government budget as well as the overall level of private consumption given in the real disposable income identity [eqn. (5.15)]. Taxation policies favoring a desired energy strategy can therefore be analyzed in detail.

Indirect business tax function:

$$\begin{aligned} TAXES &= \underset{(25.2)}{\eta_1 0.106pGRP_{\$70}} + \underset{(5.9)}{16.85} \\ R^2 &= 0.975,\ se = 5.16,\ d = 0.29 \end{aligned} \tag{5.18}$$

The income tax function used in MACRO has a surprising result. It is impossible to estimate corporate and personal income tax functions without taking tax rate changes over time into account. The total income tax *TAXDIR* function, however, applies to the entire 1960–1978 period. During these years, the average income tax rate was 33% of national income; changes in tax structures seem to have affected only the relative share of each tax category, leaving the total fairly constant. The scenario parameter $\eta_2$ in eqn. (5.19) may be interpreted similarly to $\eta_1$ in eqn. (5.18).

Income tax function:

$$\begin{aligned} TAXDIR &= \underset{(66.9)}{\eta_2 0.33pNI_{\$70}} - \underset{(5.5)}{14.19} \\ R^2 &= 0.996,\ se = 4.76,\ d = 1.39 \end{aligned} \tag{5.19}$$

The main determinants of government transfer payments are the number of retired persons and the compensation given to unemployed persons. The level of government transfer payments to persons is linked to per capita consumption in current terms. This allows the welfare system to participate in the improvement of economic production and prevents recipients of transfer payments from suffering income losses through inflation.

Government transfer payments to persons:

$$GT = \underset{(2.52)}{2.637}(POP > 65 + UNEMP) + \underset{(13.92)}{82.101}p(C_{\$70}/POP) - \underset{(-3.47)}{87.337} \tag{5.20}$$

$R^2 = 0.998$, $se = 3.17$, $d = 1.33$

*Demography*

The occupied population is obtained by dividing the demand for manhours by the number of annual hours worked. The difference between labor supply (labor force participation) and the occupied population yields the unemployment level.

Occupied population:

$$POPOCC = 1000MH^{\mathrm{R,D}}/(52HOURS) \tag{5.21}$$

Unemployed population:

$$UNEMP = L^{\mathrm{S}} - POPOCC \tag{5.22}$$

*The Trade Sector*

The importance of the trade balance equation for capital formation was discussed in Section 4. The levels of exports and nonenergy imports in MACRO are linear functions of gross regional product in current prices and are meant to reflect historically observed trade patterns. It is obvious that such simple relationships, lacking a connection with the level of world production and relative world prices, are not capable of identifying in full past determinants of exports and imports. The scenario parameters $\eta_3$ and $\eta_4$ make these relations useful in their present form, by allowing modelers to manipulate the trade sector according to their long-term perceptions of future world trade. Furthermore, such a configuration of relations encourages linkage with other more detailed trade models (i.e., models for the seven IIASA regions). In such cases exports and imports are totally exogenous to MACRO.

Trade balance:

$$TB = X_{\$70} - (p_x/p_m)^{-1}M_{\$70} \tag{5.23}$$

Exports:

$$p_x X_{\$70} = \eta_3 \underset{(28.0)}{0.287}p0.01GRP_{\$70} - \underset{(5.9)}{36.871} \tag{5.24}$$

$R^2 = 0.981$, $se = 10.28$, $d = 1.30$

Nonenergy imports:

$$p_{NEI}M^{\mathrm{N}}_{\$70} = \eta_4 \underset{(28.1)}{0.240}p0.01GRP_{\$70} - \underset{(5.0)}{26.184} \tag{5.25}$$

$R^2 = 0.981$, $se = 8.56$, $d = 1.48$

Requirements for energy imports in physical terms [tons of coal equivalent (tce)] are an output of the MESSAGE model. The factor 14.29, based on a price of US$2.75 per barrel of oil in 1970, is used to convert tce into constant 1970 monetary units.

Energy imports:

$$M^{\mathrm{E}}_{\$70} = 0.0143/E^{\mathrm{I}} \tag{5.26}$$

Total imports:

$$M_{\$70} = M^{\mathrm{E}}_{\$70} + M^{\mathrm{N}}_{\$70} \tag{5.27}$$

The import price index is determined by the energy import price index $p_I^{\mathrm{index}}$ (output from the MESSAGE model) and the nonenergy price index, weighted according to their quantities. Optionally the nonenergy import price index $p_{NEI}$ may be exogenously determined (i.e., determined outside the model loop) or linked to MACRO's overall price index.

Import price index:

$$p_M = 100(M^{\mathrm{E}}_{\$70} p_I^{\mathrm{index}} + M^{\mathrm{N}}_{\$70} p_{NEI})/(M^{\mathrm{E}}_{\$70} + M^{\mathrm{N}}_{\$70}) \tag{5.28}$$

*The Energy Sector*

MACRO obtains information on the investment and manpower requirements of the energy sector from IMPACT. Primary, secondary, and imported energy is provided by MESSAGE. MACRO combines the IMPACT output to calculate the energy sector's capital stock [see eqn. (5.8)] and real value added. Furthermore, MACRO transforms the energy import quantities into monetary terms and then uses them as variables in the determination of total imports and the trade balance [see eqn. (5.27) or eqn. (5.23)].

The energy sector's real value added can be determined in two ways: first, by applying the equilibrium prices and remuneration of labor and capital by means of the production exhaustion requirement; second, by using a Cobb–Douglas production function, which assumes diminishing returns to scale. This strong assumption is based on the expectation that the capital : output ratio of the energy sector will rise. Bauer et al. (1980) state that capital requirements will increase in all energy subsectors, not only in electricity generation. Production of synthetic fuels through coal liquefaction or gasification as a substitute for oil is especially capital intensive. Further, the characteristics of oil at the turn of the century will be quite different from the low cost, clean, and easily manageable fuel we have used during past decades. In the twenty-first century, oil will have to be extracted from dirty sources such as oil shale and tar sands, using complex and capital-intensive processes. Strict environmental protection standards will increase the capital requirements of the energy sector.

Production exhaustion requirement for the energy sector:

$$V^{\mathrm{E}}_{\$70} = p_L M H^{\mathrm{E}} + p_K K^{\mathrm{E}}_{\$70}$$

Production function (Cobb–Douglas) for the energy sector:

$$V^{\mathrm{E}}_{\$70} = 1.83(K^{\mathrm{E}}_{\$70})^{0.485}(MH^{\mathrm{E}})^{0.267} \tag{5.29}$$

The parameters in this production function are derived from the share of payments to the primary input factors capital and labor. The equation is calibrated for the reference year 1970.

*Prices in MACRO*

Real prices for capital, labor, and energy are derived from the assumption that the production factors are rewarded their marginal products [see eqns. (4.2) to (4.6)]. Renormalization of eqns. (5.1)–(5.3) for $p_K$, $p_L$, and $p_E$ yield real equilibrium prices for capital, labor, and energy, respectively.

An interesting indication of the influence of higher energy prices on the overall price level $p$ is given by eqn. (5.30). The exogenously supplied implicit price deflator for the real value added of the ROE sector $p_V$ is combined with both the energy price (calculated within MACRO) and the amount of energy supply (provided by MESSAGE):

$$p = (V_{\$70}\, p_V + Ep_E(E)p_E^{\mathrm{index}})/(V_{\$70} + Ep_E(E)) \tag{5.30}$$

## 6 MODEL VALIDATION AND TESTING

### 6.1 Validation against Historical Data

One test of a model's validity is to compare model results with actual data for a sample period. The degree to which the simulation output matches historical observations provides an indication of the model's "goodness of fit". In an equilibrium model of the MACRO type, of course, complete accuracy cannot be achieved. The assumption of an economy in equilibrium – in reality, an exceptional circumstance – forces the model to achieve an artificial equilibrium level in its solution for each time period.

Furthermore, because MACRO is a quasi-*potential* model, it postulates full utilization of all factors of production (including full employment) at the equilibrium level. This is likely to lead the simulation to slightly underestimate actual data for boom periods, when aggregate demand usually exceeds aggregate supply. The simulation may be expected to adhere best to actual developments during periods of continuous and smooth growth, when gains in productivity are distributed between factors of production so as to keep the spending of income in a constant relation to overall output, without noticeable inflation or unemployment. During periods of stagnation or recession, model output is likely to overestimate actual data.

Existing economic and demographic statistics, especially those compiled by the Statistical Office of the European Communities,[15] were used to compare model output with empirical data over the 1965–1976 period. In these validation runs, the values of all exogenous variables[16] were set equal to historical values. Figures 8–10 show model results compared with actual data for components of aggregate demand, secondary energy demand,

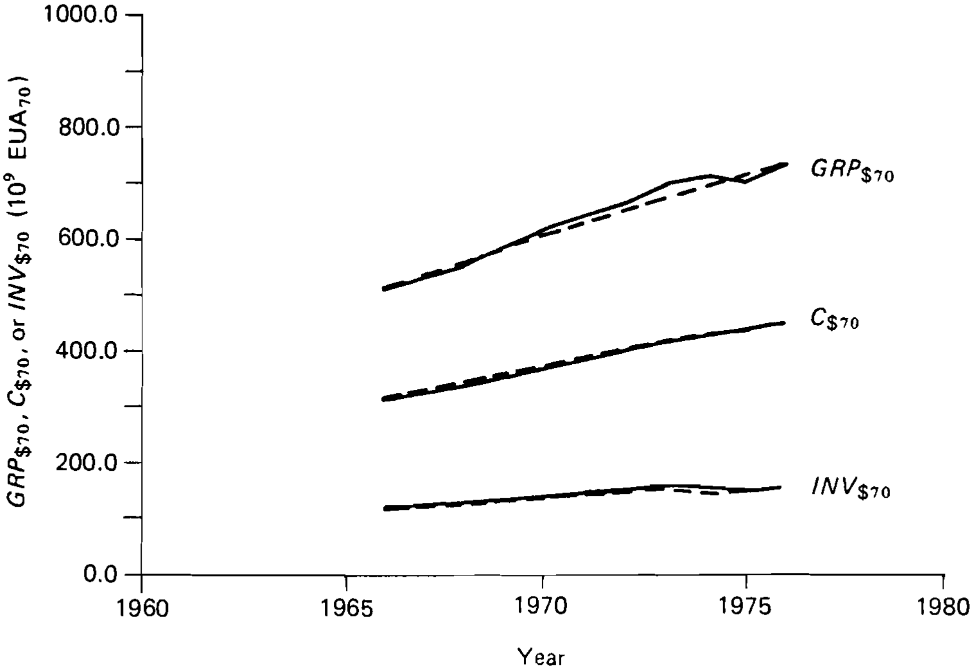

FIGURE 8 Validation of MACRO results for gross regional product $GRP_{\$70}$, personal consumption expenditures $C_{\$70}$, and gross fixed capital formation $INV_{\$70}$: - - - -, model results; ——, actual data for the EC region, 1966–1976.

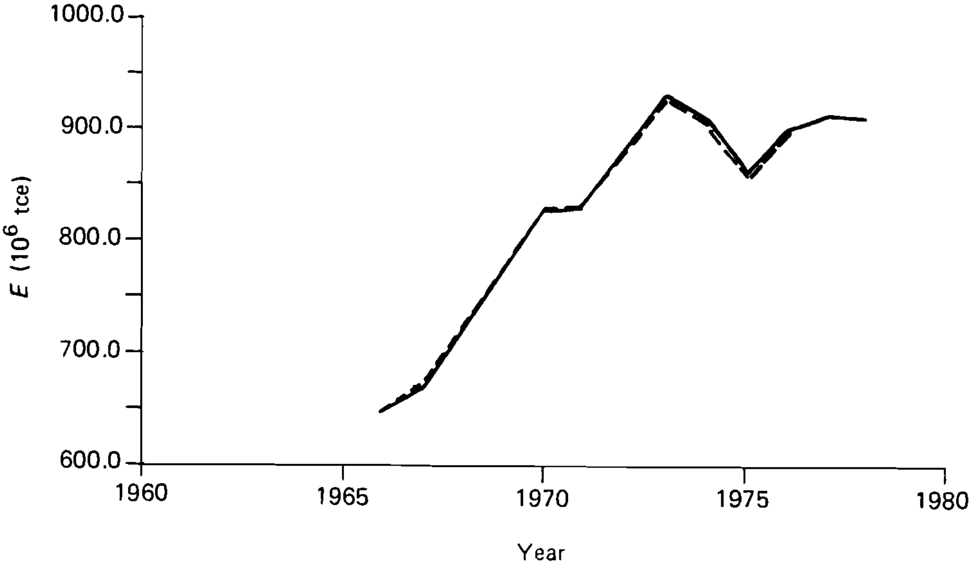

FIGURE 9 Validation of MACRO results for secondary energy demand $E$: - - - -, model results; ——, actual data for the EC region, 1966–1976.

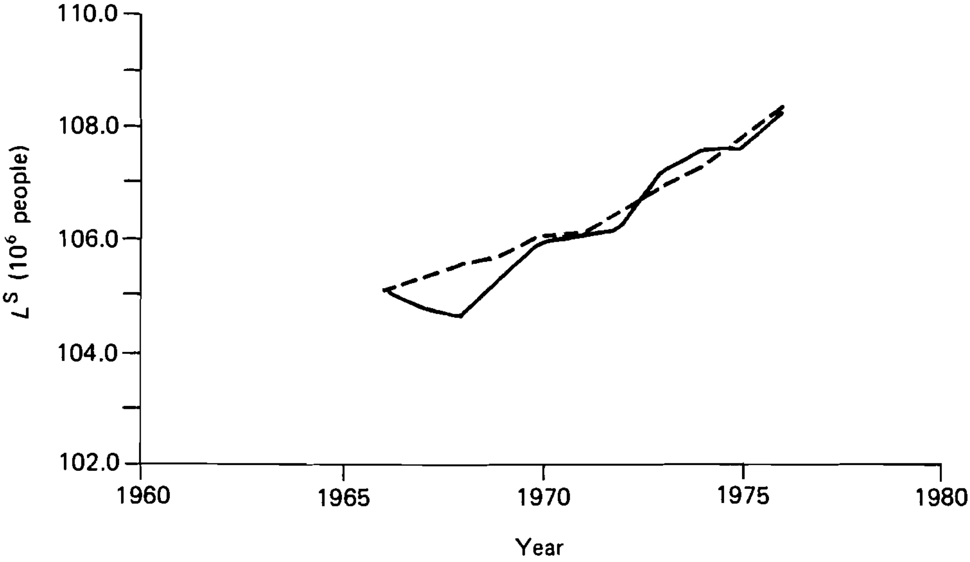

FIGURE 10 Validation of MACRO results for total labor supply $L^S$: - - - -, model results; ——, actual data for the EC region, 1966–1976.

and labor supply. In general, MACRO results for the 10-year period provide a satisfactory fit to actual data, despite the fact that the model is designed for longer-term analysis.

As may be discerned from Figure 8, the model solution for gross regional product $GRP_{\$70}$ conforms quite well to actual values between 1966 and 1976. However, the model underestimates actual developments during the period 1972–1974, when the EC economy was definitely not in equilibrium. The model results overestimate the historical trend during 1975 and 1976, when a recession produced a slowdown in economic activity: the solution values only weakly indicate the noticeable drop in economic activity that occurred in 1975.

Similar patterns can be found in the cases of gross fixed capital formation $INV_{\$70}$ and private consumption $C_{\$70}$, also shown in Figure 8. For secondary energy demand $E$, the solution values closely replicate the considerable energy demand reduction that occurred in EC member countries after 1974 (see Figure 9). For labor supply $L^S$, model results were also in line with actual values during the sample period, as illustrated in Figure 10.

## 6.2 Simulation of a 1965 Energy Crisis: A Test Case

In another type of test run, the model's predetermined (i.e., exogenous) variables were given values that simulated an energy shock to the EC region. The results of the run showed possible economic responses to the imposed disturbance. In concrete terms, the test case examined the impacts on the EC economy that could have occurred if energy-exporting countries had curtailed oil production and instituted new oil-pricing policies in *1965* instead of 1973/1974.

The purpose of this test case was twofold. First, as a type of *ex post* validation, it checked whether the model's response to the artificial imposition of a crisis situation replicated the aftermath of the real 1973/1974 energy shock. Second, it permitted examination of economic and social adjustment to the shock over the time span of a decade, rather than just for the years that have passed since 1974.

An analytical framework for the analysis of the economic adjustment process is presented below. Then the values of the exogenous variables used in the test case are specified, to show how the crisis situation was simulated in the model runs. Finally, MACRO results for the test case are presented, showing in quantitative terms the adjustment of the EC economy to the energy shock.

### *Economic Adjustment to an Energy Crisis: An Analytical Framework*

Fried and Schultze (1975) have distinguished three phases within the adjustment process. In the initial phase, rapidly increasing oil import prices raise the general price level, and, simultaneously, cause a transfer of income from consumers to producers of energy. An immediate consequence is a fall in aggregate demand and a lower level of national employment in the oil-importing countries. In turn, the oil-exporting countries accumulate a large fraction of their sudden profits from the oil sales as an unspent financial surplus, lacking a domestic infrastructure in which to spend the income.

In the second, or "transition phase", the oil-producing countries start to recycle their oil revenues by gradually increasing purchases from oil-importing countries. At the same time, oil-importing industrialized countries revitalize their domestic energy production facilities in response to the higher market price of energy (i.e., submarginal energy resources and production technologies become economically competitive). Substitution of other types of energy for imported oil, as well as price-induced conservation among energy consumers, gradually decrease industrialized countries' demand for oil and other energy products.

In the third phase, energy consumers complete their adjustment to higher energy prices by consuming less energy at higher costs. The increasing volume of exports to energy-producing countries, combined with higher domestic energy production costs, continue to keep economic growth lower than the level that would prevail in the absence of the energy pricing and production policies of the oil-producing countries. The sectoral generation of value added shifts from domestic consumer goods to export goods and services, as higher energy prices reduce domestic budgets for consumer goods, and as economic resources (exported goods and services) are drained to energy-producing countries.

During this final phase, full employment can be regained, accompanied by increased mobility between economic sectors. The final consequences of the adjustment process are slightly reduced growth in the standard of living and a reduction in overall welfare development – represented by a reduction in real wages.

### *Specification of Exogenous Variables in the Test Case*

Exogenous variables in MACRO were specified as follows to simulate an energy crisis situation. The 1975 level of energy imports to the EC region was restricted so as not to exceed the 1966 level. Domestic energy production was set equal to historically observed levels. As shown in Figure 11, this assumption led to a reversed U-shaped development curve for energy imports during the period 1966–1976. Energy import prices were assumed to leap by 20% annually, causing the domestic market price of energy to increase by roughly 12% per year – equivalent to a 4.5% annual increase in real terms for the 10-year period.

The growth rate of productivity was assumed to decline, in comparison with historically observed developments, since the drain of economic resources associated with the higher energy import bill would reduce the incentive of private business to invest in new plants and equipment. This was assumed to lead to a one-third reduction in the growth rate of labor productivity over the period 1966–1976.

*Impact of the "1965 Energy Crisis" on the EC Region*

MACRO runs based on the above assumptions have produced quantitative measures of the impacts of an assumed 1965 energy crisis in the EC region. These include estimates of the trade balance, the growth of the gross regional product, the real wage rate, the development of the per capita consumption rate, and the level of employment that result from the imposed disturbance. Analysis of the values of these variables over the period 1966–1976 provides a picture of the dimensions and speed of the adjustment process.

The macrodynamic impact of the 1965 energy crisis is closely connected to the unfavorable change in the terms of trade caused by the higher energy import prices. Figure 12 contrasts the EC region's actual oil bill (in deflated terms) for the 1966–1976

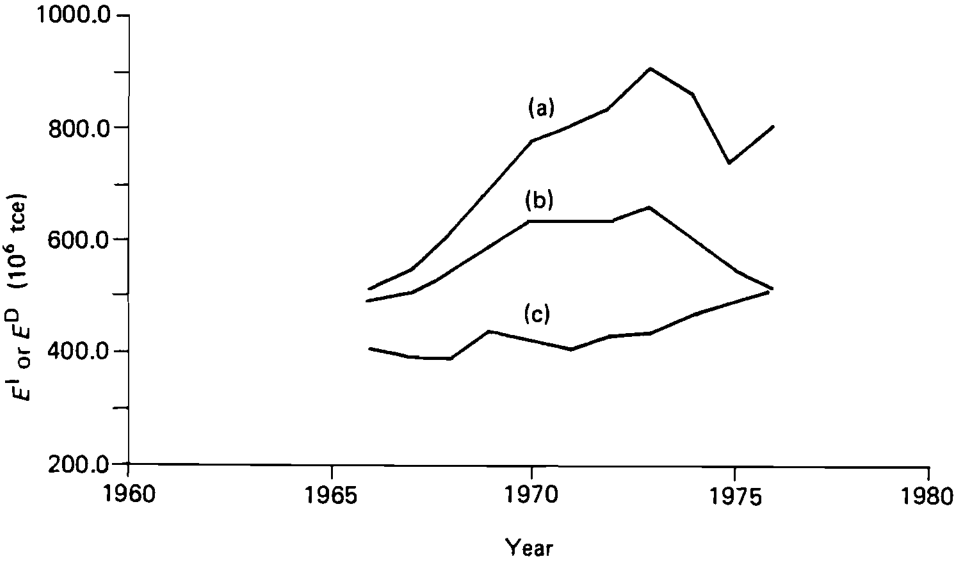

FIGURE 11 Comparison of energy imports $E^I$ assumed in the "1965 Energy Crisis" Scenario (curve b) with actual data for the EC region (curve a), 1966–1976. Curve c shows the region's actual domestic energy production $E^D$.

period with the bill in the "1965 Energy Crisis" Scenario. The cumulative difference between the results of the test case and actual data for the 10-year period amounts to $102.1 \times 10^9$ European Units of Accounts (EUA), corresponding to a $156.5 \times 10^6$ tce difference in the total quantity of imported oil. Figure 13 shows the development of the trade balance [cf. eqn. (4.9b)] resulting from the imposed oil-pricing policy.

The real loss in income associated with the higher energy prices negatively affects the savings rate, leading to reduced economic growth rates and a fall in the profit rate. This, in turn, has a negative multiplier effect on capital formation. The capital stock of an economy increases slowly over time whenever net capital formation is positive and decreases when net capital formation is negative. Thus, although the effects are not felt immediately, higher energy prices keep the rate of capital formation below historically observed levels and ultimately slow the growth of capital stock. As energy prices increase, the relatively high inelasticity of capital stock temporarily depresses the interest rate by approximately 5% for a period of several years before it regains its original level.

In quantitative terms, the GRP growth rate drops from 3.68% per year to 2.57% per year over the time frame of the test case, as indicated by Figure 14. The transfer of real income from consumers to producers of energy and cost-propelled inflation are reflected in the disproportionate decline in the per capita consumption rate, which drops from 3.6% to 1.9% per year (in real terms).

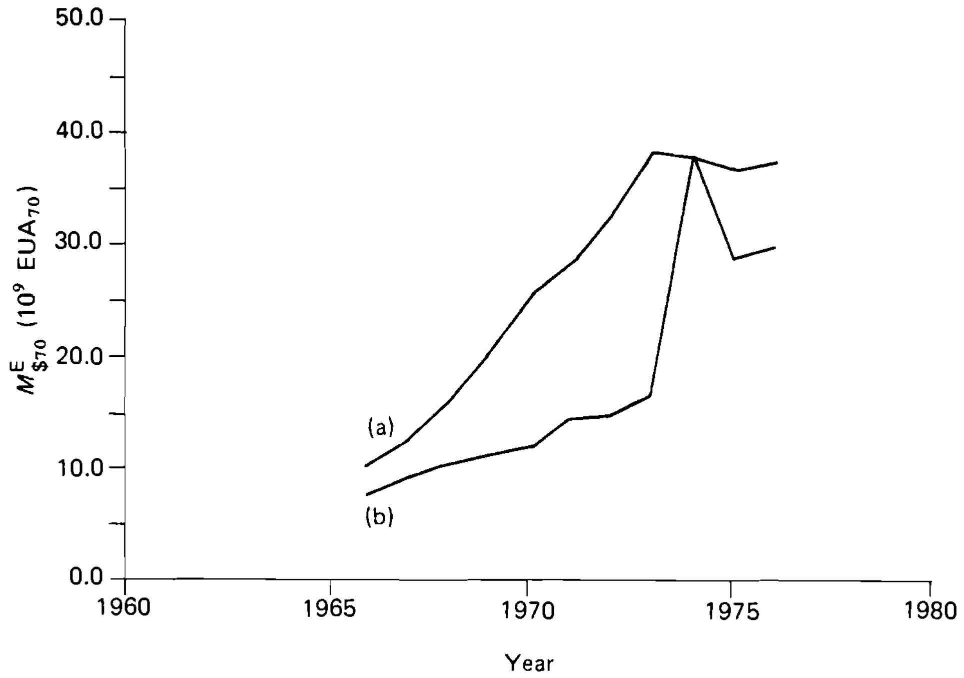

FIGURE 12 Comparison of the oil import bill $M^{E}_{\$70}$ calculated in the "1965 Energy Crisis" Scenario (curve a) with actual data for the EC region (curve b), 1966–1976.

FIGURE 13 Comparison of the trade balance *TB* calculated in the "1965 Energy Crisis" Scenario (curve b) with actual data for the EC region (curve a), 1966–1976.

The level of regional unemployment rises from about $2.0 \times 10^6$ people in 1965 to $6.7 \times 10^6$ people in 1968, corresponding to an unemployment rate of 6.4%. By 1976, the processes of substitution and adjustment of capital and labor for energy reduce the unemployment rate to less than 2.5%. Supply of labor is kept fixed at its actual value in the model run; otherwise the model's equilibrium feature would have adjusted the supply of labor to meet demand via the wage rate, and actual unemployment would have been disguised.

As shown in Figure 15, the high level of employment at the end of the test period is accompanied by a significant diminution in real wage rates. In real terms, the annual wage increase is cut from 3.9% to 2.8%. Although this allows demand for labor to return to precrisis levels, the EC economy cannot recover fully by the end of the test time frame and return to business as usual.

In general, the response of the EC economy to the simulated 1965 energy crisis follows the adjustment process described by Fried and Schultze.[17] Reduced energy import availability, combined with rapidly increasing energy import prices, reduces demand for capital or the incentive to invest within the EC region. In turn, the downward adjustment in the equilibrium quantity of capital slows the growth of gross regional product and causes unemployment to increase. Then, as climbing energy prices lead to increasing

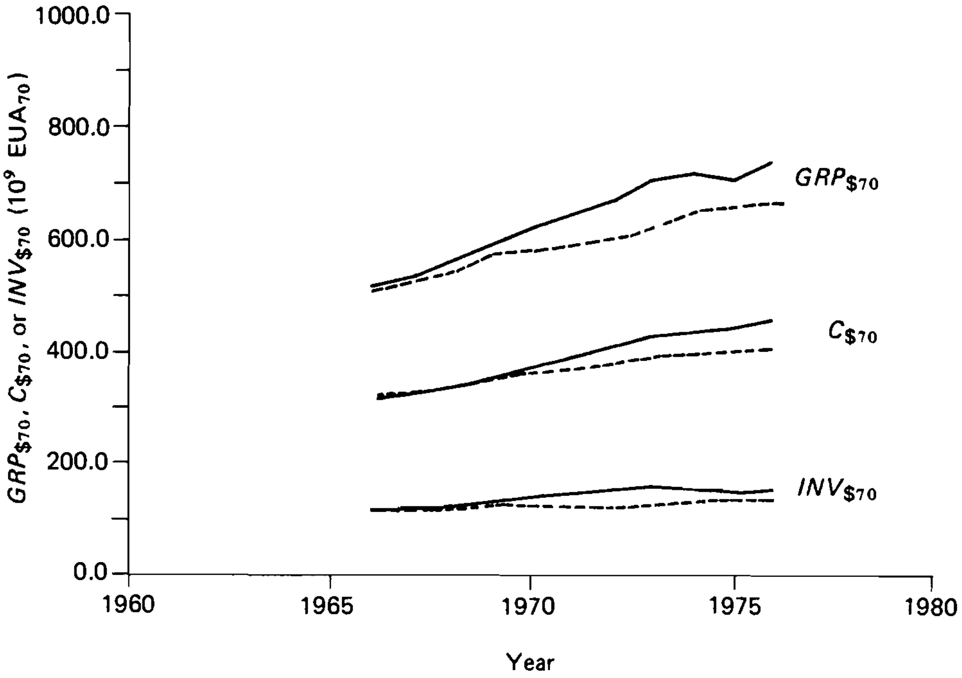

FIGURE 14 Comparison of the gross regional product $GRP_{\$70}$, personal consumption expenditures $C_{\$70}$, and gross fixed capital formation $INV_{\$70}$ calculated in the "1965 Energy Crisis" Scenario (- - - -) with actual data for the EC region (———), 1966–1976.

substitution of labor for energy-intensive production technologies and products, energy demand slows and demand for labor grows. By 1975/1976 full employment is reestablished, but at the cost of a significantly reduced real wage rate.

A comparison of the results of the MACRO run with actual events following the 1973/1974 energy shock shows that the model replicated the decline in gross regional product, the negative balance of payments, and the drop in investments, but did not account for the increased unemployment rates and the high market interest rates.

## 7 ASSUMPTIONS FOR THE LONG-TERM APPLICATION OF MACRO

MACRO was developed to study the energy–economy linkage in a regional context, specifically in the context of the European Community. This requires specification of the future framework of the region's economy, in terms of variables and parameters not handled endogenously in MACRO. For example, one crucial subset of variables concerns demographic developments over the next 50 years. Other information needed to run MACRO up to the year 2030 involves determination of such factors as relative prices for nonenergy products and overall evolution of productivity.

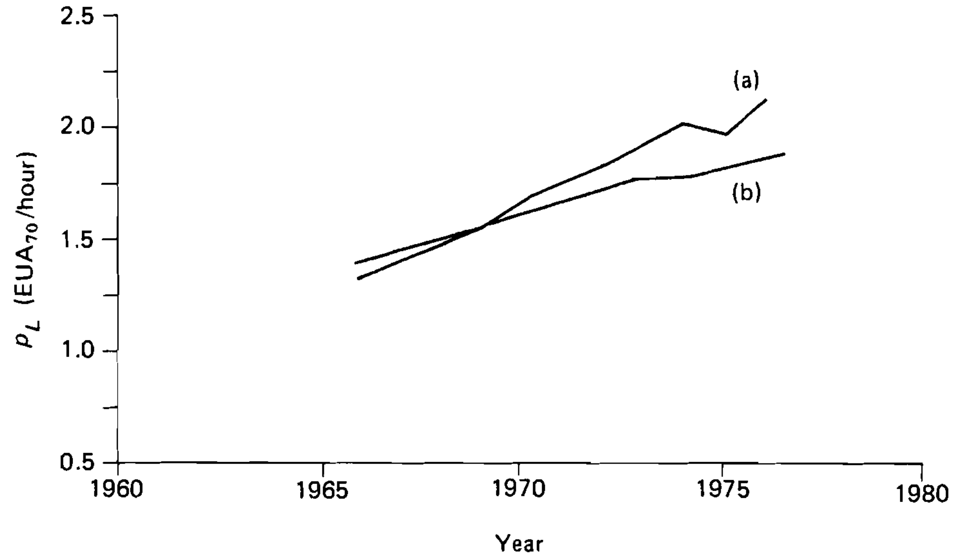

FIGURE 15 Comparison of the real wage rate $p_L$ calculated in the "1965 Energy Crisis" Scenario (curve b) with actual data for the EC region (curve a), 1966–1976.

## 7.1 Demography

The European Community is an industrialized region characterized by low and gradually declining population growth. During the period 1950–1975, its population grew steadily at 0.72% per year, compared to a prewar annual growth rate of more than 1.4%. A large fraction of the present population growth rate may be traced to persons from member states of the British Commonwealth who have emigrated to the United Kingdom, to inhabitants of former French colonies who have emigrated to France, and to "guest workers" from the Balkans and Turkey who are employed in the Federal Republic of Germany – rather than to native Europeans inhabiting EC countries. Over the next 50 years industrialization of the immigrants' low-income home countries will lessen their incentive to move to the high-income EC region. It is thus to be expected that the EC region will attain, asymptotically, a quasi-zero population growth rate by the year 2030. The population projection underlying the MACRO runs is the same as that used in a study published by the Commission of the European Communities, which in turn was partly based on the IIASA set of energy models (CEC 1980).

The fraction of the population over 65 years of age has increased substantially over the last decades, due to improved health care and welfare systems, as well as to declining fertility rates. In 1960, 10.7% of the total population was over 65; by 1975 this share had risen to 13.3%. Figure 16 shows the development of total population and the population aged over 65, as assumed in the MACRO runs. The population growth rate for the 2000–2030 period is about 0.22% per year, while the share of the population of retirement age amounts to 16.7%.

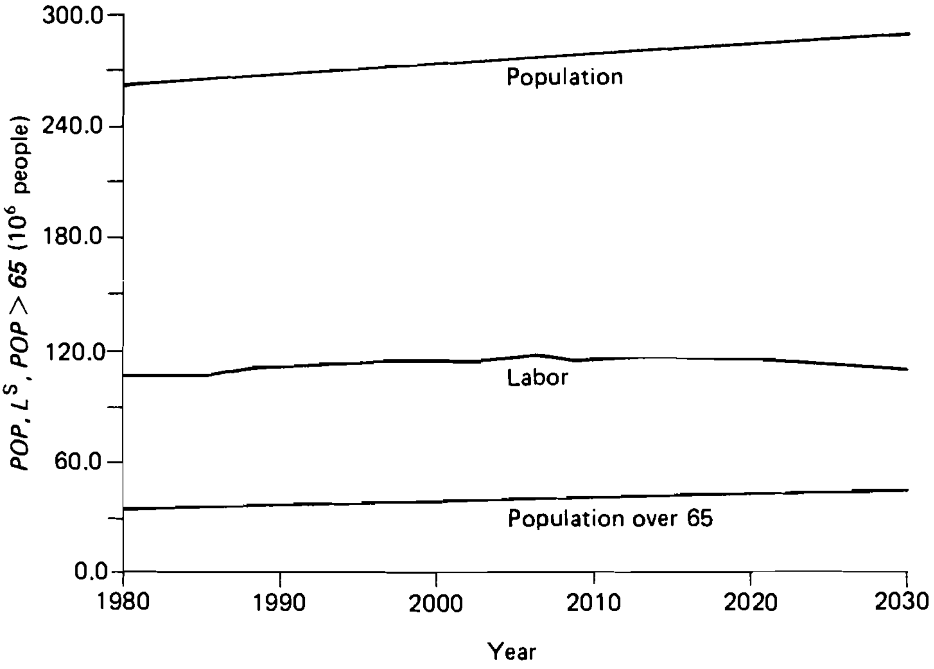

FIGURE 16 Projections of total population *POP*, labor force $L^S$, and the population over 65 $POP > 65$ used in MACRO runs for the EC region, 1980–2030.

Like the population growth rate, labor force participation has shown a retrogressive tendency during the past 20 years. In 1960 44.5% of the total population was in the labor force; by 1970, this fraction had dropped to 42.1%, and by 1975 it amounted to only 41.6%. This trend is assumed to continue in the scenarios developed by IIASA researchers for the European Community, resulting in a final labor force participation rate of 35% in 2030, as indicated in Figure 16.[18]

The exogenous specification of labor is not, however, a strictly binding restriction in MACRO. Because the equilibrium and price adjustment feature of the model determines labor supply and demand endogenously, the exogenously determined supply of labor serves only as a rough guideline. The long-term application of the econometrically estimated labor supply function given in eqn. (5.5) is limited by the inherently short-term trends prevailing in the 17-year sample period. Over a planning horizon of 50 years, these short-term trends may push labor supply unreasonably far above or below the exogenously given trend. In this case the parameters in eqn. (5.5) have to be manually adjusted to keep the endogenously calculated labor supply within reasonable bounds – at about the levels shown in Figure 16.

Another exogenously determined scenario variable[19] is the evolution of average working hours per week. Technical progress has not only allowed real wages to grow steadily over the last decade, but has also permitted the shortening of the number of working hours per week. Trade unions constantly negotiate for the reduction of the number of working hours to achieve a more humane working environment. In the light of the increasing substitution of electronic devices for labor-intensive activities and the major shift of labor requirements from production to control tasks, a decline from 44.4 working hours per week in 1970 to 32.3 hours per week by 2030 was assumed in MACRO runs.

### 7.2 Relative Prices

It is practically infeasible to determine relative prices exogenously for a 50-year period in the future. Nevertheless, inputs needed for MACRO include the specification of price indices for the value added that is produced by the ROE sector, for exports, and for nonenergy imports. The best one can do to supply these inputs is to assume the continuation of historically observed time trends of various price deflators and to perform a straightforward extrapolation of these trends. The price deflator for the ROE sector has doubled every 15–20 years since World War II, corresponding to an annual growth rate of 3.5–4.7%. Increasing energy prices are to be expected for at least another 20 years, so a 5% growth rate until the turn of the century for the value-added deflator appears reasonable. After the year 2000 a reduced rate of 3.5% has been applied, corresponding to the lower boundary of the historically observed trend. As a preliminary approach, exports and nonenergy import prices have been linked to the development of the *GRP* deflator. Inclusion of a more detailed model, to serve as a vehicle for improving the price representation of foreign sectors within the IIASA set of energy models, is under discussion.

### 7.3 Productivity

The estimated growth of the first productivity term $\theta$, introduced in eqn. (4.27) to calculate value added in the ROE sector, came to 2.95% per year during the 1960–1978 sample period. This growth rate was assumed to prevail until 1990 and then to decrease slightly. By the turn of the century, the growth rate of productivity is assumed to be 2.5% per year, and by the end of the planning horizon (2030), this rate has decreased to 2.0% per year. Of course, the values assumed for this productivity parameter are quite arbitrary and reflect a somewhat conservative view of future economic and technical development. The evolution of the productivity term represents one of the most important scenario variables, serving as a means for manipulating the model to reflect an individual's personal view of the future. (This also holds for all other exogenous variables.)

The growth rate of the second productivity term $\gamma$ was assumed to remain at 1.146% per year until the turn of the century, and then to gradually approach zero growth by 2030. This decline in productivity is meant to reflect, in part, the increasing environmental constraints negatively affecting the capital : output ratio in many sectors of the economy. Capital and the efficiency of capital continue to be dominant factors in determining overall productivity.

The downward trend in productivity also reflects the change in the age distribution of the population. The increasing proportion of people over 65 will lead to a more service-oriented economic structure – representing a break from the past industrialized society in the direction of a postindustrialized economy. In the OECD's "Interfutures" study (OECD

1980), the term "change in values" is used to represent the change in the population's attitude toward the past composition of the social product (*GRP*). According to this study, such changes in values are likely to occur in response both to changes in the environment and to changes in conceptions of the significance of man's existence. The decline in the average number of working hours per week can definitely be interpreted as a significant shift away from a purely production-oriented society.

## 8 FOUR SCENARIOS FOR THE EUROPEAN COMMUNITY

The four scenarios presented below depict a range of energy futures for the European Community. Scenario 1 is characterized by unlimited availability of energy at reasonable costs. It represents a return to historically observed economic growth patterns – as if the 1973/1974 energy crisis had only been a short-term market disruption. Scenario 2 is a more realistic reference scenario, assuming tight constraints on energy availability and steadily increasing energy prices. Scenario 3 focuses on energy demand, examining the feasibility of strong assumptions about price-induced energy conservation. Finally, Scenario 4 considers the EC's future energy supply infrastructure, which is likely to be marked by high capital requirements.

These scenarios are used in this section as the setting for examination of specific energy-related macroeconomic questions. For instance, the MACRO applications described below focus on such issues as the impact of restricted energy imports on economic growth; the implications of reduced energy availability for the development of gross domestic product, wages, the trade balance, and other economic variables; the compatibility of high economic growth rates with low growth in energy requirements and high energy prices; and the impact of capital deepening in the energy sector on the rest of the economy. These are issues with which the European Community is currently grappling and thus illustrate MACRO's capacity to provide input for discussions of economic policy.

### 8.1 Scenario 1: A Reference Case

*Assumptions*

Scenario 1 may be called a *business as usual* case. It is assumed that the EC economy will not face energy import shortages in the future, i.e., that the present 55–60% energy import share within total energy supply will be sustained. Thus, energy is supplied in sufficient quantities and at prices comparable to those prevailing in the 1974–1976 postcrisis period. It is furthermore assumed that the foreign trade sector will continue to operate as historically observed. The world export market absorbs excess domestic production and required imports are available without limit – implying perfect market conditions. The current energy supply and demand structure thus remains unchanged, as do capital requirements per unit of production capacity.

Essentially, conditions characterizing the period 1960–1973 are extrapolated to the years after 1980. The period 1974–1979 is considered a transition phase, during which economic disruptions caused by the steep increase in energy prices in 1973/1974 are resolved. By the end of the decade, when the economy has fully readjusted to the higher energy price levels, a new level of economic equilibrium is achieved. The energy-producing countries' 1973/1974 oil policy is thus taken to be a one-time interference in the world energy market.

The scenario specification also includes skewing of the age distribution to the older age groups and slowing of improvements in productivity.

### *Results*

What, then, are the macroeconomic implications of the energy future defined by these assumptions? MACRO's output, in the form of indicators of economic development over a 50-year planning horizon, are summarized in Tables 1 and 2. As may be expected from the scenario specification, this scenario is characterized by a gradually declining economic growth rate. During the period 1985–2000, the growth rate of the gross regional product equals 3.9% per year; by the period 2015–2030, it has dropped to 2.6% per year.

In line with the economic mechanism built into MACRO, the effects of the 1973/1974 oil curtailments and the subsequent steadily increasing energy import prices encourage implementation of energy-conserving technologies through the substitution of capital and labor for energy. The impact of this substitution process on energy intensiveness (defined as the ratio of secondary energy to gross regional product), however, only becomes apparent 10–20 years later. If energy intensiveness in 1970 is set equal to 100, then this index drops to 77.3 by the year 2000 and to 74.8 by 2030 (see Table 1). These improvements in energy intensiveness cause secondary energy demand in ROE to grow at a lower rate than in the past.

TABLE 1 Results of the MACRO run for Scenario 1: values of selected variables over time.

| Variable | Year | | | | |
|---|---|---|---|---|---|
| | 1970 | 1985 | 2000 | 2015 | 2030 |
| Gross regional product ($10^9$ EUA at 1970 prices and exchange rates) | 618.2 | 1061.4 | 1875.3 | 2958.6 | 4358.2 |
| Secondary energy ($10^6$ tce) | 830.8 | 1218.8 | 1948.0 | 2942.5 | 4281.3 |
| Investment rate (%) | 22.8 | 21.9 | 20.9 | 19.5 | 18.8 |
| Energy intensity (1970 = 100) | 100.0 | 85.4 | 77.3 | 74.0 | 74.8 |
| Price of energy [EUA/tce (deflated)] | 30.4 | 60.2 | 64.8 | 74.8 | 71.3 |
| Capital: output ratio | 3.59 | 3.53 | 3.31 | 3.19 | 3.13 |

TABLE 2 Growth rates of selected variables, by time period, in Scenario 1 (% per year).

| Variable | Time period | | | |
|---|---|---|---|---|
| | 1960–1973 | 1985–2000 | 2000–2015 | 2015–2030 |
| Gross regional product (at 1970 prices and exchange rates) | 4.5 | 3.9 | 3.1 | 2.5 |
| Secondary energy | 4.6 | 3.2 | 2.8 | 2.5 |
| Consumption per capita | 3.7 | 3.6 | 3.0 | 2.4 |
| Secondary energy per capita | 3.8 | 3.0 | 2.6 | 2.3 |

The energy–GRP elasticities corresponding to these levels of energy intensiveness are 0.82 for the period 1985–2000 and 0.97 for the period 2000–2030. The slowdown in the rate of improvement of energy intensiveness after the turn of the century results from unconstrained energy supply, for this hinders the innovation process from progressing beyond the necessary levels imposed by the first-order optimality condition of the production function.

Although Scenario 1 is admittedly highly artificial, it provides a reference point for assessing the degree to which the other scenarios deviate from a simple continuation of business-as-usual into the future. The difference between the results for Scenario 1 and those of the other scenarios show the economic impact of less optimistic assumptions for the energy future, including restricted energy import quantities and high energy prices.

## 8.2 Scenario 2: A Constrained Energy Supply Case

### *Assumptions*

In Scenario 2 some assumptions used in Scenario 1 have been modified to produce a reference case based on a more realistic view of the future. This view is characterized by reasonably optimistic assumptions about the implementation of energy conservation measures and improvements in energy efficiency.

The most important difference between Scenarios 1 and 2 concerns energy availability. In Scenario 2, energy import quantities are assumed to be restricted and energy import prices are correspondingly high. It is postulated that by the year 2030 no more than 45% of primary energy requirements can be met by imports. At the same time, the energy import price index is assumed to increase at the high rate of 7.5% per year until the turn of the century, when it begins a gradual decline to 5% per year by 2030. Domestic energy production is constrained to a maximum annual growth rate of 2.5%. Assumed levels of energy imports and domestic energy production over the scenario time frame are shown graphically in Figure 17.

Capital requirements per unit of production capacity in the energy sector are assumed to rise from the present value of 0.27 EUA/watt to 0.62 EUA/watt by the year 2030. Demographic and productivity assumptions are held constant in Scenarios 1 and 2.

### *Results*

The results of Scenario 2 are summarized in Tables 3 and 4. Reduced quantities of energy imports, together with the constrained expansion of domestic energy production, have significant negative consequences for the EC economy, causing GRP growth rates to fall well below those attained in Scenario 1. By 2030, secondary energy supply is reduced to 59% of that available in Scenario 1, while the value of GRP at an equilibrium stage represents only 81% of the value calculated for Scenario 1.

The braking effects of reduced energy supply on economic activity are partly offset by substitution of capital and labor for energy. The capital : output ratio is a good indicator of such substitution: technical progress and sufficient energy supply allow this ratio to decrease from 3.59 in 1970 to 3.13 in 2030 in Scenario 1; in Scenario 2 it reaches a value of only 3.28 by 2030.

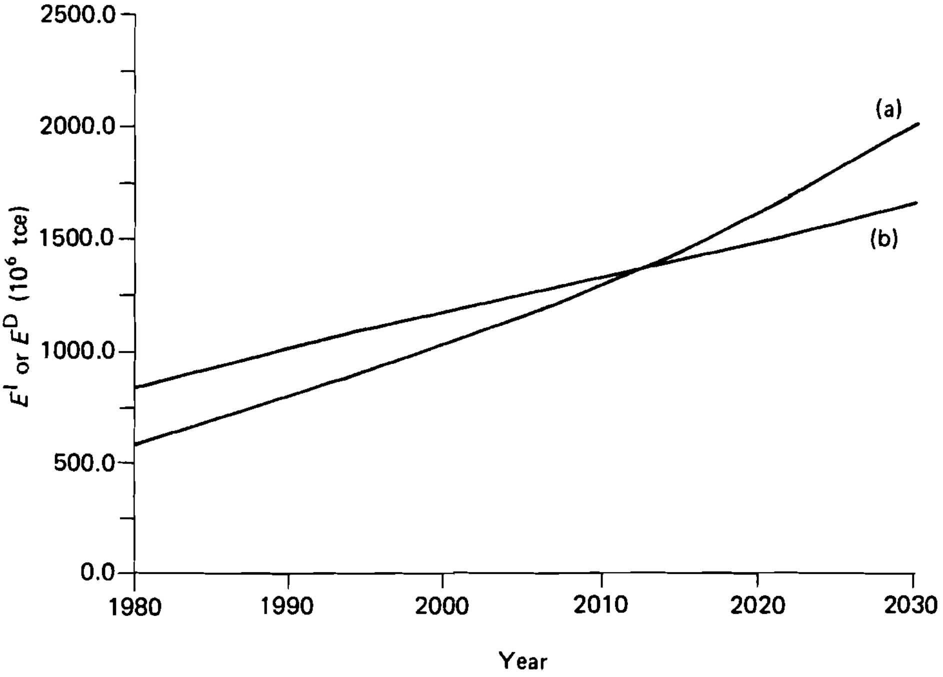

FIGURE 17 The development of energy imports $E^I$ (curve a) and domestic energy production $E^D$ (curve b) assumed in Scenario 2, 1980–2030.

TABLE 3 Results of the MACRO run for Scenario 2: values of selected variables over time.

| Variable | Year | | | | |
|---|---|---|---|---|---|
| | 1970 | 1985 | 2000 | 2015 | 2030 |
| Gross regional product ($10^9$ EUA at 1970 prices and exchange rates) | 618.2 | 1035.0 | 1734.8 | 2558.0 | 3521.2 |
| Secondary energy ($10^6$ tce) | 830.8 | 1118.8 | 1510.2 | 1948.8 | 2514.9 |
| Investment rate (%) | 22.8 | 21.6 | 20.5 | 19.0 | 17.7 |
| Energy intensity (1970 = 100) | 100.0 | 80.4 | 64.8 | 56.7 | 53.2 |
| Price of energy [EUA/tce (deflated)] | 30.4 | 59.6 | 63.0 | 165.2 | 200.4 |
| Capital: output ratio | 3.59 | 3.58 | 3.38 | 3.33 | 3.28 |

TABLE 4 Growth rates of selected variables, by time period, in Scenario 2 (% per year).

| Variable | Time period | | | |
|---|---|---|---|---|
| | 1960–1973 | 1985–2000 | 2000–2015 | 2015–2030 |
| Gross regional product (at 1970 prices and exchange rates) | 4.5 | 3.5 | 2.6 | 2.2 |
| Secondary energy | 4.6 | 2.0 | 1.7 | 1.7 |
| Consumption per capita | 3.7 | 3.3 | 2.6 | 2.0 |
| Secondary energy per capita | 3.8 | 1.8 | 1.5 | 1.5 |

Reduction of the secondary energy demand to match a given level of energy supply is performed in MACRO by adjusting the price of energy to its equilibrium level. Comparison of Table 1 with Table 3 shows that the deflated price of energy in 2030 is a factor of 2.68 higher in Scenario 2 than in Scenario 1. The energy price in 2030 corresponds to an annual growth rate of 3.2% above overall inflation.

Although scenario assumptions hardly affect labor requirements in Scenario 2, they do result in a reduction in real wages. As may be seen in Figure 18, the real wage rate drops from 14.5 EUA/hour in 2030 in Scenario 1 to 12.1 EUA/hour in Scenario 2 to permit maintenance of full employment. Full employment is not a surprising result, for MACRO's equilibrium feature does not allow underutilization of labor unless otherwise specified.[20]

The effects of steadily increasing energy prices on the trade balance become noticeable only after the year 2010 in Scenario 2. Before the turn of the century, higher energy import prices are directly offset by the physical reduction in energy import quantities. After the year 2010, the slowdown in overall economic activity increases the share of the energy import bill relative to the bill for nonenergy imports. Together with declining export volumes (in relative terms), this results in a negative trade balance. The unfavorable trade balance in turn lessens the incentive of private business to invest in new plants and equipment and has a negative multiplier effect on economic output. As shown in Table 3,

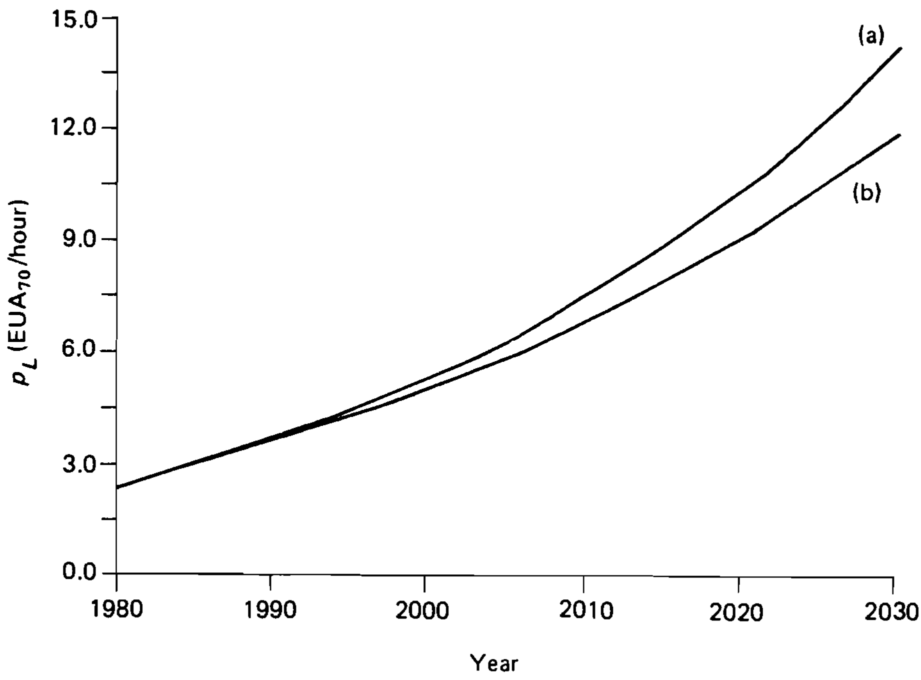

FIGURE 18 Comparison of the real wage rate $p_L$ calculated in Scenario 1 (curve a) with that calculated in Scenario 2 (curve b), 1980–2030.

this sequence of impacts results in a low investment rate of 17.7% in 2030. (Export quantities are not adjusted to produce an equilibrated trade balance in this scenario.)

The results of Scenario 2 clearly indicate the negative effects of reduced energy inputs on economic growth, as well as the strong influence of higher energy prices on the economy. But one should bear in mind that, due to the structure of MACRO, substitution processes between factors of production are solely regulated by their market prices. Other factors that encourage substitution, such as institutional measures or innovations introduced independently of energy prices, are not considered in the model.

## 8.3 Scenario 3: Energy Demand versus Energy Prices – A Consistency Check

Within the IIASA model loop, the level of future energy demand is derived from MEDEE, and the costs and prices to satisfy this demand are calculated in MESSAGE and IMPACT. MACRO may be used to provide a check on the consistency of various assumptions used in these models at different points in the modeling exercise. Scenario 3 addresses this vital question, focusing on the consistency between energy demand lowered through strong conservation assumptions and associated energy prices.

### *The Nature of Energy Conservation*

However high the uncertainties, estimates of future energy needs must be made to evaluate the implications of alternative future energy supply systems and to study the probable dynamics of the energy–economy linkage, including economic adjustment to scarcer and more costly energy. The range of future energy requirements calculated in various long-term studies is quite large [see Workshop on Alternative Energy Strategies (1977), World Energy Conference (1978), and CEC (1980)]; since assumptions about demographic and economic development are often nearly identical in the studies, differences in estimated future energy demand stem from diverse views of the potential of energy conservation.

Energy conservation does not have to be associated with energy curtailments or energy shortages. Rather, it implies careful and intelligent use of energy, leading to improvements in energy efficiency. In general, it is useful to distinguish between *price-induced* and *lifestyle-induced* conservation.

In the case of price-induced conservation, lowered availability of energy and accompanying price increases may lead to the substitution of capital, labor, and expertise for energy, thus decoupling the historically close relationship between GNP and energy use. The process of adjustment to lowered availability of energy in a competitive economy is mainly governed by the price of energy. Increases in price can depress the equilibrium economic output – since any price-induced deviation from the optimal input profile constitutes a shift away from the previously achieved optimum – unless other factor prices decrease concommitantly. If wage rates are lowered, firms are encouraged to replace energy-intensive production technologies with labor-intensive methods. The multiplicative effect of augmented labor input can even increase GNP [see eqn. (4.10)].

Lifestyle-induced conservation spans a wide range of human activities and involves fundamental changes in values (see Section 7.3). For instance, private households may decide to allocate their budgets to less energy-intensive activities and thus cut down on energy used for private travel. The trend of movement into large urban areas could also conceivably be reversed as part of a growing general aversion to large-scale technologies. In addition, energy use may be affected by saturation effects concerning the material goods that underlie the standard of living of the industrialized world. These changes in values imply a structural change from a production-oriented to a more service-oriented economy. Shifts in a region's age distribution may also contribute to this structural change.

*The Characteristics of Scenario 3*

Scenario 3 was developed to study the consistency between MEDEE-generated estimates of energy demand and underlying assumptions about energy prices. Case 2 of the CEC's study "Crucial Choices for the Energy Transition" (CEC 1980) provided a good starting point for the consistency check, for MEDEE had been used to calculate energy demand for the case, under strong assumptions of energy conservation.[21] Underlying assumptions concerning lifestyle-induced conservation and improvements in energy efficiency were considered correct; the focus in the consistency check was rather on the validity of the price-induced conservation assumptions used in the demand calculations for Case 2.

Briefly stated, the consistency check involved using the level of energy demand estimated in the CEC's Case 2 as input to MACRO, calculating the associated equilibrium price level, and, finally, comparing the price yielded by MACRO with that assumed in Case 2. As will be shown below, the results of the consistency check in fact revealed that the price assumptions underlying Case 2 were *not* consistent with the levels of energy demand calculated for the case.

The feature of Scenario 3 that distinguishes it from Scenario 2 is then the use of the energy demand calculated in the CEC's Case 2 as an exogenous input. (Actually, to suit MACRO's requirements, the energy demand had to be converted to secondary energy supply; but because MACRO is an equilibrium model, supply is taken to equal demand.) As illustrated in Figure 19, this assumption results in a markedly lower level of energy supply in Scenario 3 than in Scenario 2. All other assumptions are held constant in the two scenarios.

*Scenario Results*

MACRO's response to the assumptions used in Scenario 3 is shown in Tables 5 and 6. The low level of energy availability pushes the price of energy up to 301.8 EUA/tce by the end of the scenario time frame. This is equivalent to an annual increase of 9% in current terms, bringing the price of a barrel of oil up to 64 US dollars (at 1970 US prices and exchange rates). At this price equilibrium level, economic output is about 12% below that of Scenario 2. The investment rate of private business concurrently drops to 16.3% of GRP, certainly a reaction of producers to the transfer of income to energy-producing countries. The energy intensiveness index in Scenario 3 drops by approximately 6 percentage points to 47.5 (1970 = 100) by 2030.

The energy prices calculated by MACRO for Scenario 3 are clearly higher than those assumed in the CEC's Case 2. The iterative procedure built into MACRO, which permits it to find an equilibrium between a given quantity of available energy and the internally calculated energy demand, yielded a 3.7% annual growth rate for the real equilibrium energy price of secondary energy over the period 1975–2030. Corresponding current

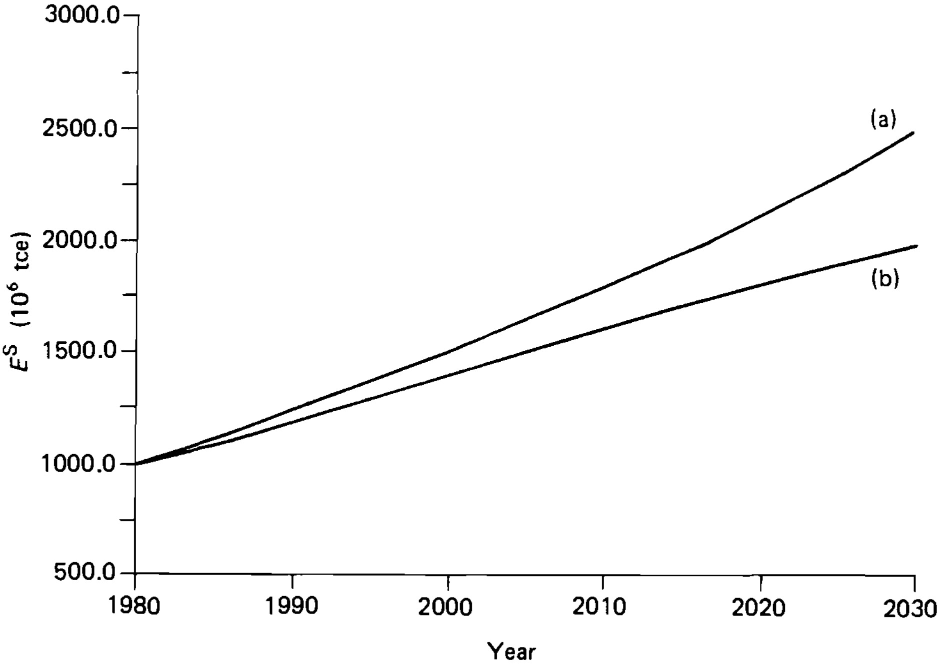

FIGURE 19 Comparison of the secondary energy supply $E^S$ assumed in Scenario 2 (curve a) with that assumed in Scenario 3 (curve b), 1980–2030.

TABLE 5 Results of the MACRO run for Scenario 3: values of selected variables over time.

| Variable | Year | | | | |
|---|---|---|---|---|---|
| | 1970 | 1985 | 2000 | 2015 | 2030 |
| Gross regional product ($10^9$ EUA at 1970 prices and exchange rates) | 618.2 | 1030.1 | 1692.5 | 2432.9 | 3109.7 |
| Secondary energy ($10^6$ tce) | 830.8 | 1081.6 | 1401.1 | 1715.3 | 1985.7 |
| Investment rate (%) | 22.8 | 21.6 | 20.2 | 18.3 | 16.3 |
| Energy intensity (1970 = 100) | 100.0 | 78.1 | 61.6 | 52.5 | 47.5 |
| Price of energy [EUA/tce (deflated)] | 30.4 | 64.8 | 128.4 | 214.5 | 301.8 |
| Capital: output ratio | 3.59 | 3.57 | 3.41 | 3.33 | 3.30 |

TABLE 6 Growth rates of selected variables, by time period, in Scenario 3 (% per year).

| Variable | Time period | | | |
|---|---|---|---|---|
| | 1960–1973 | 1985–2000 | 2000–2015 | 2015–2030 |
| Gross regional product (at 1970 prices and exchange rates) | 4.5 | 3.4 | 2.4 | 1.6 |
| Secondary energy | 4.6 | 1.7 | 1.4 | 1.0 |
| Consumption per capita | 3.7 | 3.2 | 2.5 | 1.6 |
| Secondary energy per capita | 3.8 | 1.5 | 1.2 | 0.7 |

price increases for imported and domestically produced energy amounted to 8% and 11%, respectively. These values range well above the price development assumed in the CEC's Case 2: there the price of imported energy was assumed to increase by 5% per year, while the price of domestic energy was assumed to increase by 6% per year.

A small test was carried out with MACRO to elucidate this price inconsistency between Scenario 3 and the CEC's Case 2. In this test the *price development* assumed in Case 2 was used as input to MACRO, instead of energy supply, and the corresponding equilibrium energy demand and its macroeconomic impacts were then calculated. Figure 20 contrasts the results of this test case with those of Scenario 3.

In the figure, the broken curves [(a) and (c)] represent real secondary energy prices and the solid curves [(b) and (d)] represent secondary energy demand. The CEC case is characterized by the lower energy demand and energy price curves [(c) and (d)].

In the test run (in which the assumed price evolution of the CEC's Case 2 was used as input to MACRO), the corresponding equilibrium secondary energy demand follows the high demand curve (b) in Figure 20. The availability of low-cost energy causes secondary energy demand to increase by a factor of 1.58 in this test case. Concurrently, equilibrium output and its major components shift upwards by 21.1%, as shown in Figure 21.

In contrast, in the MACRO run for Scenario 3 [in which the secondary energy availability shown in curve (d) is used as input], the corresponding equilibrium price follows the high price evolution shown by curve (a). *This suggests that if energy demand is to be*

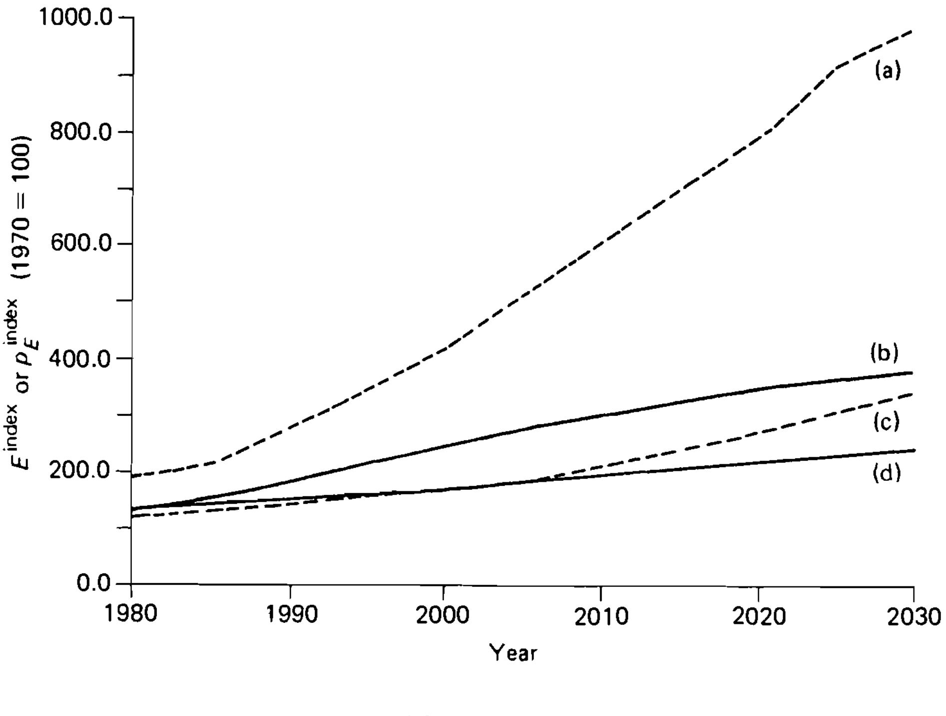

FIGURE 20 Secondary energy demand $E^{index}$ (———) and the corresponding equilibrium energy price $p_E^{index}$ (- - - -) in Scenario 3 (curves a and b) and in Case 2 (curves c and d) of the CEC study "Crucial Choices for the Energy Transition (CEC 1980), 1980–2030.

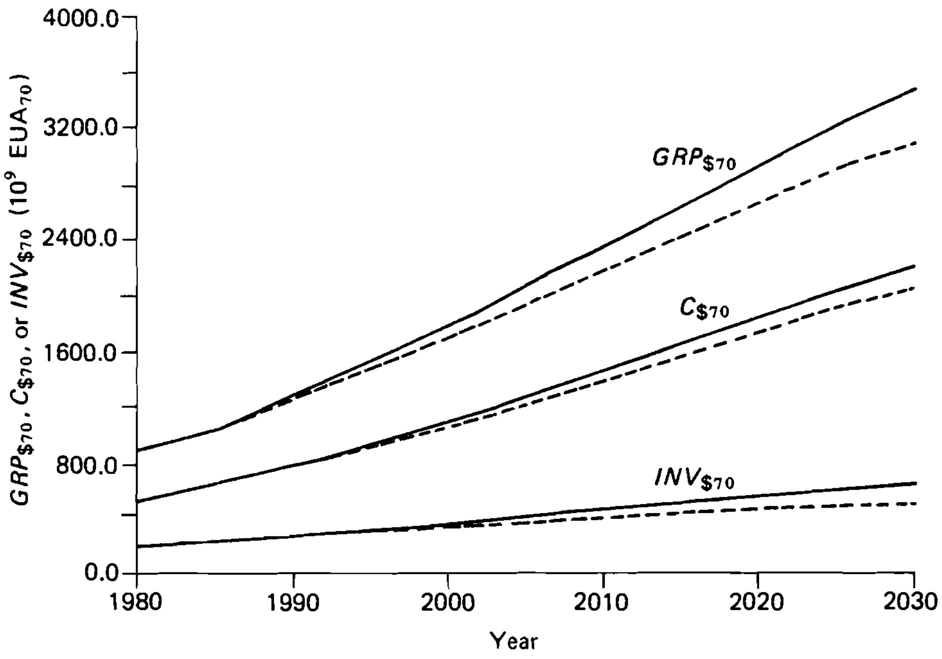

FIGURE 21 Evolution of gross regional product $GRP_{\$70}$, personal consumption expenditures $C_{\$70}$, and gross fixed capital formation $INV_{\$70}$ in Scenario 3 (——) and in Case 2 (- - -) of the CEC study "Crucial Choices for the Energy Transition" (CEC 1980), 1980–2030.

*kept at the low level of curve (d), the required price-induced conservation (and accompanying innovation) can only be achieved if energy prices accord with the high price development curve (a).*

In conclusion, the results of the MACRO run for Scenario 3 indicate that the price-induced energy conservation assumptions used in MEDEE for Case 2 of the CEC study are very optimistic, if not infeasible. The adjustment processes built into MACRO allow for a strong reduction in secondary energy demand only in connection with significantly higher energy prices and a considerable loss in national income.

### *A Note on Lifestyle-Induced Conservation in the Context of MACRO*

Scenario 3 shows clearly the problems of implementing strong energy conservation measures consistently in an aggregate macroeconomic model. MACRO determines the demand for the primary production factors (capital and labor) and for energy, under the assumption that these factors are rewarded their marginal products. Substitution between production factors is limited to relative changes in their prices and does not include efficiency improvements, unless the lower energy use resulting from such improvements is translated into additional labor or capital requirements.

Thus, probable long-run changes in consumer lifestyles, which underlie MEDEE's detailed demand analyses, cannot be represented satisfactorily in MACRO. Energy conservation measures considered in MEDEE (but not in MACRO) include potential energy savings in the household and service sector (for instance, through better insulation standards in housing and the introduction of heat pumps and soft solar technologies), advanced communication technologies, and improved mileage per unit of motor fuel in the transprotation sector.

It is possible, however, to deduce *indirectly* from MACRO improvements in energy efficiency associated with an economy subject to structural and lifestyle changes. To do so requires examination of *energy–income* and *energy–price elasticities.*[22] Over the period 1963–1973, the income elasticity $\lambda$ in the EC region amounted to 0.875 and the corresponding price elasticity $\mu$ was $-0.050$. A 1% increase in GRP thus caused energy demand to grow by 0.875%, while a 1% increase in the price of energy reduced energy demand by 0.05%. If the period 1974–1978 is included in the historical analysis, the sharp rise in energy import prices associated with the oil crisis has a strong effect on the elasticities; a comparison of the first two columns in Table 7 shows this clearly. The income elasticity drops to 0.823, while the price elasticity climbs to $-0.169$, showing the strengthened consumer response to price changes.

As part of the long-term study of the EC region, various income elasticities were assumed for the 1979–2030 planning period, and the corresponding price elasticities were calculated on the basis of Scenario 3 results. As may be seen in Table 7, a high income elasticity of 0.9 is offset by a relatively strong price elasticity of $-0.259$, while a price elasticity of $-0.114$ is associated with a reduced income elasticity of 0.7. This interdependence of income and price elasticities suggests that prices should be used carefully as an energy management tool in the future.

If high income elasticities are maintained in the coming decades, any reduction in energy demand must come from consumers' reactions to energy price increases. At the same time, permanently increasing energy prices can have a negative effect on the consumption of energy-intensive commodities, and this in turn has a negative multiplier effect on commodities complementing energy-intensive goods and services. More expensive energy imports and transfer of national income abroad have unfavorable effects on the trade balance and intensify the burden on the economy. If energy demand is manipulated only through prices, without the initiation of structural changes, losses in aggregate demand will surely result.[23]

In contrast, low income elasticities represent a substantial structural change in industrial production, as well as in lifestyles. If the economy evolves smoothly toward an advanced economic structure characterized by low income elasticities, relatively high economic growth rates and full employment can be achieved. But such a smooth

TABLE 7 Energy–income (2) versus energy–price elasticities: historical values and results for Scenario 3 under varying assumptions.

| Elasticity | Historical values | | Scenario 3 results | | |
|---|---|---|---|---|---|
| | 1963–1973 | 1963–1978 | 1979–2030 | 1979–2030 | 1979–2030 |
| $\lambda$ | 0.875 | 0.823 | 0.900 | 0.800 | 0.700 |
| $\mu$ | −0.050 | −0.169 | −0.259 | −0.186 | −0.114 |

transition takes much time – lead times are of the order of decades. Thus, any assessment of the effectiveness of energy conservation measures for the EC region must consider the high degree of inertia inherent in its social and economic system.

## 8.4 Scenario 4: The Effects of Capital Deepening in the Energy Sector

Scenario 4 focuses on the energy sector's future capital requirements and their impact on the capital available to other economic sectors. Because the composition of the EC region's future energy supply system serves as the point of departure for this analysis, it is appropriate to consider briefly the possible evolution of energy production and imports in the region, as well as associated capital needs. Overall, the regions' supply situation will be dominated by constraints – limited domestic energy resources, energy import curtailments, and time needed for capacity buildup and construction of new domestic power plants, conversion facilities, and domestic fuel extraction facilities.

### *Energy Availability in the EC Region*

Compared with demand, the fossil fuel resources of the EC region are small. Even continuously rising world market prices will not turn present submarginal domestic energy resources into economically recoverable reserves. Offshore North Sea oil and coal located at great depths currently constitute Europe's most important resources; in the future, domestic fossil resources will become even more difficult to extract. At the same time, a desire to reduce dependence on energy imports will increase the pressure on the domestic energy production sector. If the EC's policy target of restricting imported energy to a maximum of 45% of total requirements by the year 2025 is met, domestic energy production capacity will have to increase by a factor of 1.33 – without even considering the actual expansion of total energy demand.

Limited domestic fossil fuel reserves combined with the need for increased output will compel the EC to consider all potential new energy sources, including "hard" and "soft" technologies – within the limits of their realizable potential and their compatibility with existing economic and social structures. Currently, decentralized renewable ("soft") resources, such as local solar, wind, biomass, and geothermal energy, seem difficult to introduce in Europe's large urban areas. Their energy supply density, about 0.5 watt/m$^2$, is extremely low compared with current energy consumption densities of about 5 watt/m$^2$ in urban areas (World Energy Conference 1978). Still, no energy option should be excluded *a priori*; structural changes and modifications in lifestyle, such as a reversal of the past trend of movement to urban areas, may favor "soft" technologies in the future.

Advanced centralized technologies, such as nuclear power and the solar tower concept, do seem suitable for the industrialized and urbanized infrastructure of the EC region. However, the widespread introduction of these technologies is also attended by difficulties. The application of nuclear power is currently hindered by the debate over societal compatibility and safeguards. Ultimately, it will be limited by the scarcity of economically recoverable world uranium resources, unless the breeder technology is introduced on a wide scale, and long lead times are associated with this technology. The competitiveness of the hard solar option is hampered by unsolved storage problems and the magnitude of its requirements for metals, concrete, and other materials. These constraints preclude the large-scale penetration of this technology into the energy sector before 2030.

These constraints and the long lead times connected with the large-scale introduction of newer energy technologies may be expected to produce continuing reliance on liquid fuels and electricity in the EC region during the next 50 years. However, restricted oil imports and environmental concerns are likely to put emphasis on synthetic liquid fuels and advanced electricity production technologies.

### *Future Capital Requirements of the Energy Sector*

Rising capital costs for extracting coal and offshore oil will heavily influence the energy sector's future capital requirements. As domestic fossil resources become less accessible, the energy content per unit of extracted output will decrease and capital requirements per unit of installed capacity will increase. Concern for minimizing the environmental damage associated with extraction activities will also lead to higher capital costs at the beginning of the energy supply chain.

At the energy conversion stage, advanced technologies used to transform primary fuels into secondary and final energy forms will also be characterized by increasing capital intensity. Improvement of conventional conversion processes to meet environmental protection standards and parallel development of transmission and distribution systems will each augment the energy sector's capital requirements.

Replacement of the existing supply infrastructure with advanced and more capital-intensive energy production technologies, substitution of a certain share of previously imported energy through domestic production, and growth in primary energy demand will together lead to historically unprecedented capital needs in the energy sector during the next 50 years.

### *The Setting for Scenario 4*

In Scenario 4, the EC region's future energy supply requirements and associated capital costs are described in quantitative terms through application of the whole IIASA model loop. MEDEE runs provide an estimate of future energy demand; MESSAGE calculates the corresponding primary energy requirements; IMPACT then determines the capital required to create the prerequisite energy supply infrastructure; finally, the issue central to Scenario 4 – the macroeconomic implications of concentrating capital in the energy sector – is examined in a series of MACRO runs.

The socioeconomic assumptions underlying Scenario 4 are the same as those used in Scenario 3. Thus, energy prices develop according to curve (a) in Figure 20, and corresponding lifestyle trends in the household and transportation sectors include continuing increases, in absolute terms, in the size of dwellings and quantitites of electrical appliances, as well as emphasis on private cars. Not surprisingly, electricity and liquid fuels are major components of the future energy demand calculated by MEDEE on the basis of these assumptions.

The corresponding energy supply requirements provided by MESSAGE are strongly affected by the EC energy import policy of restricting imports to no more than 45% of total energy needs by 2025. This constraint produces several notable fuel substitution trends, as illustrated in Figure 22. Although the relative share of liquid fuels remains fairly constant over the scenario time frame, the share of primary energy supplied by oil – mainly oil imports – declines from over 50% in 1975 to under 20% by 2030. This results from the substitution of coal-based synthetic fuels for oil and the accompanying replacement of coal by nuclear power for electricity generation. Hydropower and gas maintain their

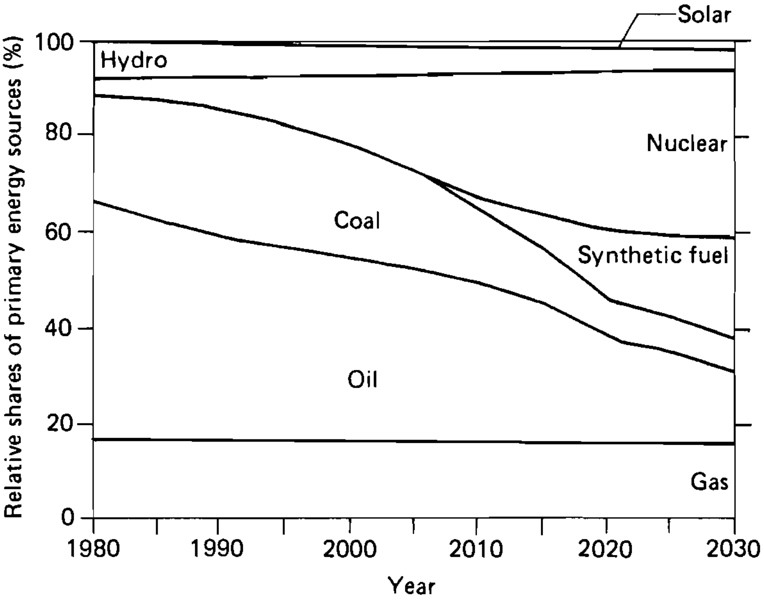

FIGURE 22 Primary energy shares by sources calculated for the EC region, Scenario 4, 1980–2030.

relative market shares, while, for reasons discussed above, renewable energy resources (represented by solar power in Figure 22) contribute little to overall energy supply.

IMPACT runs based on this energy supply configuration showed a 150% increase in the specific energy capital stock per watt of production capacity between 1970 and 2030. Expressed in constant 1970 monetary terms, capital stock increases from 0.27 EUA/watt in 1970 to 0.67 EUA/watt in 2030. The energy sector's capital stock as a share of total stock increases from 7% in 1970 to 16% in 2030.

In Figure 23 a continuation of the historical trend[24] of investments in the energy sector over the next 50 years is contrasted with the investment requirements calculated by IMPACT for Scenario 4. The accumulated difference between the two curves up to the year 2030 amounts to 720 X $10^9$ EUA. Such a gap makes one ask whether the economy can raise enough additional capital to avoid a capital shortage in the energy sector, given the supply assumptions of Scenario 4.

This question is addressed in two successive MACRO runs. The first run investigates the impact of the energy sector's rapidly increasing capital: output ratio on interest rates and the profitability of its capital. The second run examines a government intervention strategy for boosting the profitability of the energy sector's capital to levels prevailing in other economic sectors.

### *Run 1: Assumptions and Results*

In the first MACRO run for Scenario 4, the impact of capital deepening in the energy sector is analyzed without taking into consideration the traditionally assumed benefits of multiplier and acceleration effects. In other words, the rapid growth of the capital: output

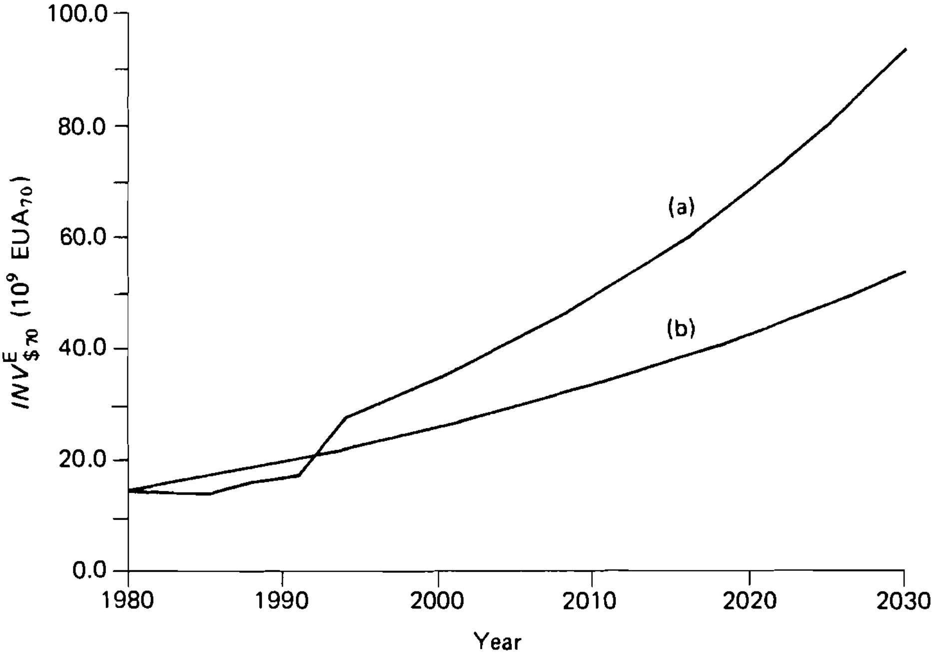

FIGURE 23 Comparison of projected requirements for gross fixed capital formation $INV^E_{\$70}$ in the energy sector of the EC region in Scenario 4 (curve a) with a continuation of the historical trend, 1980–2030 (curve b).

ratio in the energy sector is assumed to occur without corresponding increases in value added in this sector. Thus, the additional capital neeeded to fill the gap between the two curves in Figure 23 is taken to be unproductive in the traditional macroeconomic sense. Purchases of investment goods by the energy sector from other sectors may certainly induce multiplier and accelerator effects in those sectors. But an aggregate two-sector model is not designed to account for intersectoral growth effects.

The results of Run 1 show that the strong assumption about the growth of capital stock in the energy sector has a clear impact on the rest of the economy. In order to allocate sufficient capital to the energy sector and to balance total capital demand and supply, the model pushes the equilibrium real interest rate[25] for the economy as a whole about 2% above the historical 9–10% level by the end of the scenario time frame. The divergence between these results and an extrapolation of historical trends is shown in Figure 24.

Thus the higher level of overall capital demand and the requirement that the capital needs of the energy sector must be met result in higher overall capital prices. This in turn implies either that productivity and efficiency improvements occur to ensure an equivalent increase in capital profitability or that the rest of the economy reduces its propensity to invest – a direct consequence of the equilibrium condition in which the marginal product of capital must match the price of capital (i.e., the interest rate).

The response in Run 1 is a fall in the absolute quantity of investments in the rest of the economy. The level of investment is 7.5% lower than in Scenario 3 (in which it is

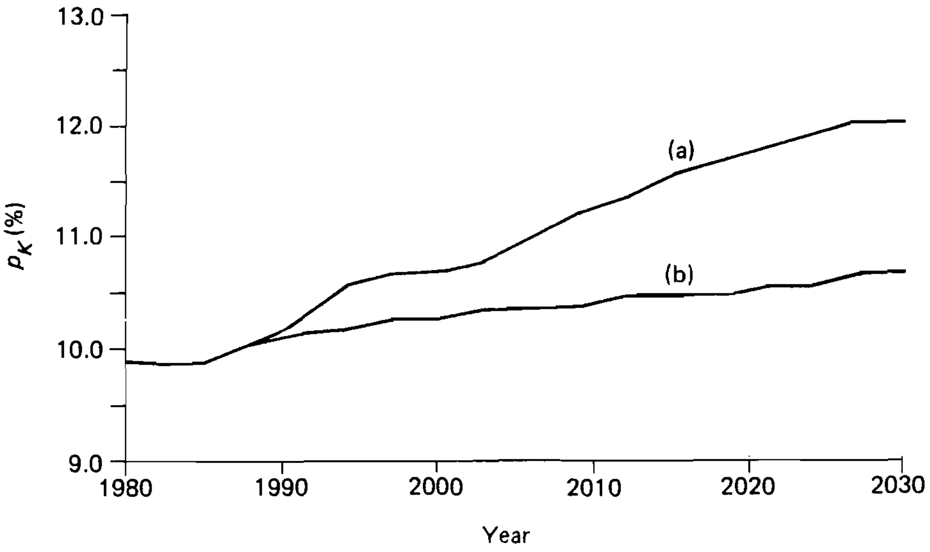

FIGURE 24 Comparison of the evolution of the cost of capital $p_K$ (real interest rate) in Scenario 4 (curve a) with a continuation of the historical trend, 1980–2030 (curve b).

assumed that historical trends of investment in the energy sector continue). Thus, given a 2% increase in the rate of return of investments, 7.5% of the previously profitable investments in the rest of the economy fall below the level of economic feasibility. The reduction in the investment volume in the rest of the economy would correspond to about 90% of the additional capital requirements associated with the energy sector in Scenario 4.

However, as the equilibrium interest rate increases, the profitability of the energy sector's capital concurrently drops by 60%, to a low of 4.5%, to avoid violating the constant value-added constraint imposed on the sector in this run. In a market economy, the decline in the levels of capital profitability in the energy sector would certainly result in a capital drain from that sector to other sectors, since shareholders and capital lenders would not invest in submarginal objects whose interest is two-thirds lower than the prevailing market interest on capital. *This implies that the energy sector would not have access to the capital needed for Scenario 4's energy supply configuration, without some form of intervention on the capital market.* Accordingly, the second MACRO run for Scenario 4 simulated such intervention.

### *Run 2: Government Intervention on the Capital Market*

MACRO is able to simulate one type of adjustment to capital deepening in the energy sector through manipulation of the *income tax scenario parameter* [see parameter $\eta_2$) in eqn. (5.19)]. MACRO calculates the amount of annual subsidies required to compensate capital owners in the energy sector with the appropriate market interest on capital. In an iterative procedure, the model then adjusts the income tax rate to maintain a balanced government budget, thereby reducing growth in disposable income and producing a lower level of private consumption. The decrease in private consumption is channeled, by means of the government budget, to subsidize the energy sector's returns on investment, i.e., to produce uniform interest rates and thus match the profitability of the energy sector's capital with that of the rest of the economy. The components of final demand in effect shift from personal consumption expenditures to gross fixed capital formation, without major impacts on overall economic activity.

In Run 2 the average income tax rate increases from 33.0% to 35.5% by the end of the planning horizon. The corresponding level of private consumption lies 4.5% below that which would have prevailed, given continuation of the historial energy investment and taxation trends assumed in Scenario 3. The overall impact of the stringent taxation policy assumed in Run 2, then, is a reduction in private consumption expenditures and increases in the investment rate sufficient to supply the capital needs of the energy sector.

### *The Trade Balance in Equilibrium*

Even if government intervention on the capital market does make sufficient capital available to the energy sector, the EC economy would still be confronted with a serious trade imbalance. In 2030, 45% of total energy requirements in Scenario 4 stem from foreign sources, and steadily rising energy import prices have turned the trade balance into a permanent deficit. Because the trade balance acts as an explanatory variable in the determination of investment supply within MACRO, a deficit reduces the investment supply level and reflects the economic loss of paying a higher energy import bill.

A sensitivity study based on Scenario 4 focuses on ways of eliminating problems connected with the balance of payments and international exchange rates. Specifically, the run determines the expansion in imports required to equilibrate the trade balance and examines the macroeconomic impact of increased exports. The three main assumptions underlying the run are that a negative trade balance leads the EC to strive for a higher export volume on the international export market; that the international market absorbs any excess production from the EC economy; and that the export incentive of domestic business can be manipulated through institutional measures such as taxation, export subsidies, or special export credit facilities.

These policies are simulated in MACRO through manipulation of an *export parameter* [see parameter $\eta_3$ in eqn. (5.24)]. The parameter is adjusted exogenously in the model run to eliminate the trade balance deficit by 2030. Figure 25 contrasts the resulting evolution of the trade balance in the sensitivity study with that in the regular MACRO run for Scenario 4. Figure 26 shows the markedly higher export activities calculated in the sensitivity study, compared with the export development in Scenario 4; the evolution of the energy import bill over the scenario time frame is also plotted for reference.

Table 8 summarizes the long-term economic impacts of the additional export sales stimulated by manipulation of the export parameter. Besides favorably affecting the trade balance, the expanding export activities increase the incentive of private business to invest. Consequently, economic activity is stepped up and the growth rates of the gross regional product increase. (Part of this growth is absorbed by import expenditures, since increased economic activity implies a need for more energy and other imported products.)

At the same time, personal consumption expenditures are only marginally affected, because most of the added production of goods and services must be exported to raise revenue for energy imports or must be used in the capital formation process to accumu-

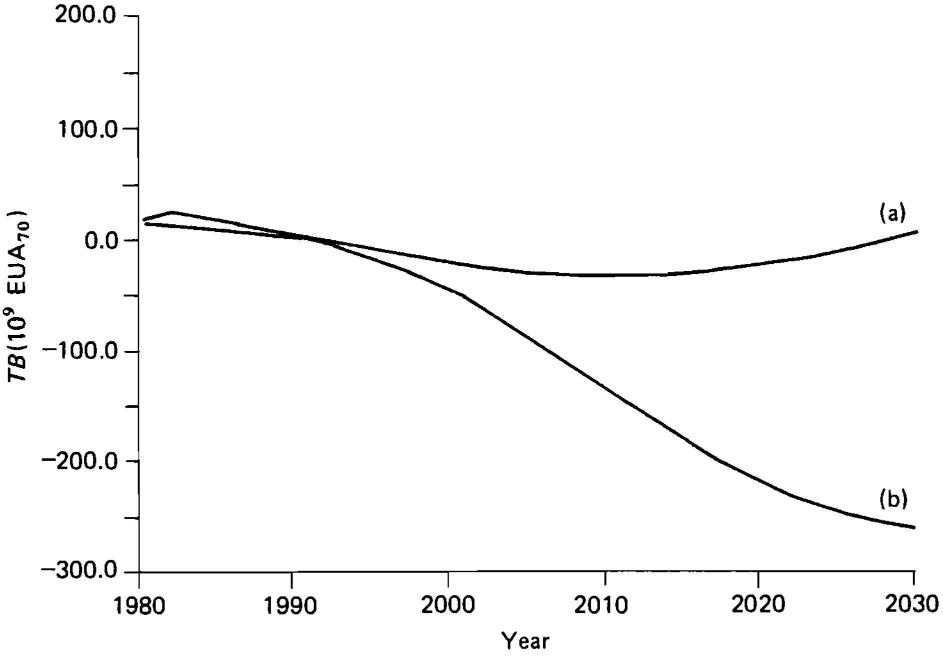

FIGURE 25 Comparison of the EC region's trade balance *TB* in Scenario 4 (curve b) with the results of a sensitivity study in which exports are adjusted to eliminate a trade balance deficit (curve a), 1980–2030.

late sufficient capital to increase overall economic activity. There is also only a relatively small increase in the required export share of gross regional product – 30.8%, compared to 29.5% in Scenario 3. This indicates the sensitivity of the EC economy to the future development of the world trade volume.

It must be stressed that equilibration of the trade balance rests on the assumption that the international trade market can in fact absorb the EC's excess exports, despite the already strong export dependence of the EC economy. Unfortunately, the present version of MACRO cannot be used to test the validity of this assumption.

In general, the results of the run indicate the pressure of the EC economy to maintain a high level of productivity and to become even more competitive on the international trade market. Effective political measures are in turn the prerequisite for stimulating productivity. A general conclusion, which may be drawn from all the MACRO runs for Scenario 4, is that *the investments necessary for diverting sufficient capital to the energy sector and for counteracting trade imbalances may not occur in the absence of effective policy.*

The world trade market is not the only wild card influencing the future growth prospects of the EC economy. It is necessary for political institutions to create the appropriate environment for businesses to invest, even in times when productivity tends to decline and economic resources are drained through unfavorable terms of trade. Without an adequate buildup of production capacities, the EC economy will not be able to react when an upswing in the world trade market does occur.

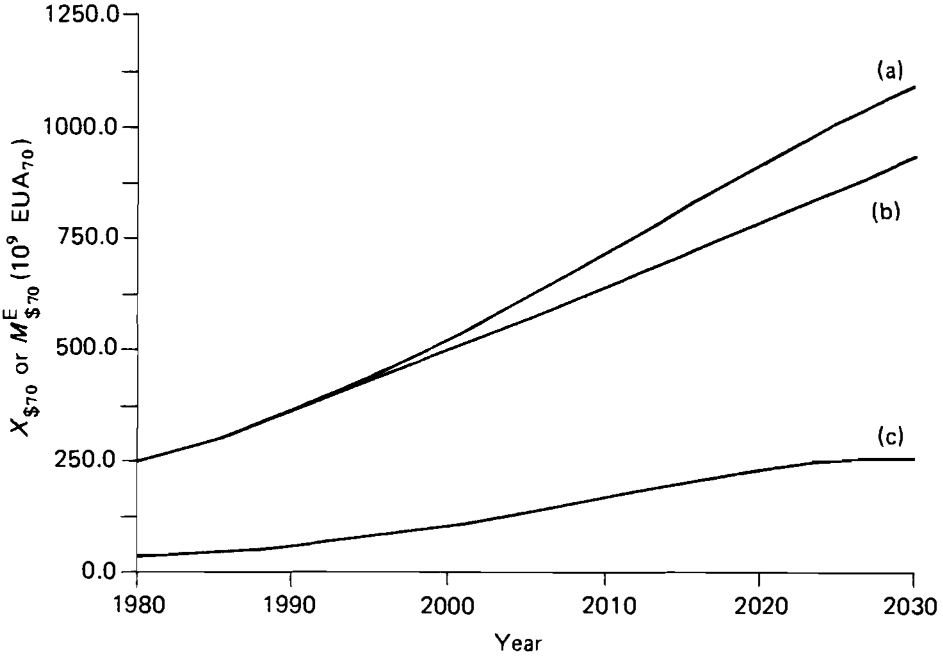

FIGURE 26 Comparison of the EC region's exports $X_{\$70}$ in Scenario 4 (curve b) with the results of a sensitivity study in which exports are adjusted to eliminate a trade balance deficit (curve a), 1980–2030. Curve c shows the development of expenditures for energy imports $M^E_{\$70}$ assumed in both cases.

### *A Comment on Productivity*

The growth rates of productivity are assumed to gradually decrease over time in the scenarios presented in this report. This is not due to a predicted decline in technical innovation, for it does not seem reasonable to assume a slackening of the human urgency for investigation and exploration. Rather, the obstacles hindering future growth in productivity will probably arise from interactions between science, technology, and society, as suggested by the OECD (1980).

For example, the debate on future energy supply systems within the member countries of the European Community has made the future development of various economic sectors uncertain. In this situation, producers tend to concentrate on reducing production costs at present production levels, instead of developing new products and introducing new processes to improve productivity. An additional factor is that modest economic growth rates may reduce long-term R&D expenditures, thus limiting the financial resources required to make high-cost technological breakthroughs.

In recent years, societal resistance has blunted many technological breakthroughs. It has been especially difficult to obtain public acceptance for the introduction of large-scale, centralized technologies. But such technologies must be adopted, if the industrialized economy of the EC region is to achieve the gains in productivity necessary to cope with future challenges. Otherwise, the region's population must be willing to live with reduced economic growth rates and significant changes in lifestyles – a possibility not entertained in the scenarios described above.

TABLE 8 Results of the MACRO run for Scenario 4 and for a sensitivity study in which exports of goods and services are adjusted to produce an equilibrated trade balance.

| Variable | Year | | | |
|---|---|---|---|---|
| | 1985 | 2000 | 2015 | 2030 |
| Exports of goods and services ($10^9$ EUA at 1970 prices and exchange rates) | | | | |
| Scenario 4 | 294.8 | 491.8 | 707.7 | 915.1 |
| "Adjusted Exports" Run | 301.9 | 502.4 | 742.0 | 997.6 |
| Gross regional product ($10^9$ EUA at 1970 prices and exchange rates) | | | | |
| Scenario 4 | 1026.8 | 1683.4 | 2402.9 | 3097.9 |
| "Adjusted Exports" Run | 1049.9 | 1687.3 | 2434.3 | 3242.8 |
| Personal consumption expenditures ($10^9$ EUA at 1970 prices and exchange rates) | | | | |
| Scenario 4 | 635.7 | 1045.7 | 1516.1 | 1971.6 |
| "Adjusted Exports" Run | 647.8 | 1042.1 | 1507.3 | 1977.3 |
| Gross fixed capital formation ($10^9$ EUA at 1970 prices and exchange rates) | | | | |
| Scenario 4 | 224.3 | 345.5 | 463.8 | 562.4 |
| "Adjusted Exports" Run | 222.5 | 346.3 | 472.6 | 621.1 |
| Investment rate (%) | | | | |
| Scenario 4 | 21.8 | 20.5 | 19.3 | 18.2 |
| "Adjusted Exports" Run | 21.2 | 20.5 | 19.4 | 19.2 |
| Personal consumption expenditures per capita ($10^9$ EUA at 1970 prices exchange rates) | | | | |
| Scenario 4 | 2.178 | 3.849 | 5.415 | 6.799 |
| "Adjusted Exports" Run | 2.457 | 3.836 | 5.384 | 6.818 |
| Capital stock in energy sector as share of total capital stock (%) | | | | |
| Scenario 4 | 7.0 | 8.5 | 11.0 | 14.8 |
| "Adjusted Exports" Run | 7.0 | 8.6 | 10.6 | 13.2 |

## 9 MODEL WEAKNESSES AND STRENGTHS

### *Model Deficiencies*

The development of a model that captures the essentials of the European Community's economy is hampered by problems of data availability. It was necessary to estimate the econometric relations within MACRO on the basis of data from the relatively short 1960–1978 (and sometimes only the 1966–1976) sample period. Because the statistical data available for the 1960–1978 period give more weight to the boom years of the 1960s than to the post–1973 economic slowdown, the attributes of short-term boom periods are inherently incorporated into MACRO's parameters.[26] The different, and even conflicting, systems of national accounts used by the nine countries that compose the aggregate EC region complicate the problem of constructing an adequate data base. Thus, much caution is required for long-term application of MACRO, due to the imperfection of the sample data and the shortness of the sample period.

A second problem is that the aggregate nature of MACRO precludes consideration of changes within and between various economic sectors. In particular, the model cannot reflect substitution effects between the factor inputs in a given economic subsector, the results of saturation of various social needs, or shifts in production from one sector to another. The difficulty of examining energy conservation measures with MACRO (as discussed in Section 8.3) provides an example of these shortcomings. An input–output model, which represents interactions between all economic sectors, would be needed to reflect such details.

A third deficiency is that MACRO's aggregate production function is based on the strong assumption that substitution between factors of production depends completely on relative prices. Of course, there are other incentives and motives for such substitution, including innovations and technical progress. Consideration of these factors would require the detailed description of sectoral production functions that account for all types of input factors, including materials. MACRO is in no position to respond to such a requirement.

The model's capabilities would also be improved if it contained an energy supply function in which higher energy prices could induce increased energy production. As the model now stands, energy supply is exogenously determined, thus limiting the model's flexibility. Finally, MACRO's equilibrium feature has to be viewed as an artificial attempt to balance demand for and supply of the primary input factors (capital, labor, and energy). In reality, an economy in equilibrium is more of an exception than a rule.

### *Model Achievements*

Despite these deficiencies, the application of MACRO within the IIASA set of energy models may be considered successful. The model fulfills the CEC's original request for a consistency check of its member countries' long-term energy demand and supply strategies. As well, MACRO's compact structure permits easy examination of various scenarios and encourages the user to test the impact of imposed normative changes on the long-term behavior of the aggregate EC economy.

The scenarios presented in Section 8 demonstrate the types of questions that MACRO is designed to answer. Because MACRO contains a two-way linkage betwen the energy sector and the rest of the economy, it can be used to examine the effect of rising energy prices on the growth of gross regional product. As shown by the difference between the results of Scenario 1 and Scenario 2, large energy price increases accompanying constrained energy availability are likely to reduce gross regional product considerably.[27] As demonstrated in Scenario 3, MACRO is able to reveal inconsistencies in assumptions originating from the other models within the IIASA set of energy models. Scenario 4 illustrates the use of MACRO to analyze the long-term effects of higher energy prices and increased capital intensiveness in the energy sector on the structure of exports and the capital market.

Despite the uncertainties inherent in long-term scenario assumptions, MACRO runs revealed the need for intensified efforts to guarantee a high level of economic productivity during the next decades. Innovation and improvements in efficiency appear to be the best approaches for coping with future energy-related (and other) economic problems.

## NOTES

1. The full-member countries of the EC ("EC of Nine") in 1979 were Belgium, Denmark, the Federal Republic of Germany, France, Ireland, Italy, Luxembourg, The Netherlands, and the United Kingdom.

2. The term "homomorphic picture" has been translated from the German concept "homomorphe Abbildung", coined by Professor Wolfgang Eichhorn.

3. MEDEE stands for "Modele de l'Evolution de la Demande d'Energie".

4. MESSAGE stands for "Model for Energy Supply Systems And Their General Environmental Impact."

5. IMPACT was developed at the Siberian Power Institute, Union of Soviet Socialist Republics. The model's name refers to the economic impacts of various energy strategies.

6. Indirect requirements are not considered in MACRO.

7. $E^{\mathrm{I}}$ and $E^{\mathrm{D}}$ are measured in physical units, i.e., in millions of tons of coal equivalent ($10^6$ tce).

8. As mentioned above, energy is treated totally as an intermediate good in MACRO. Therefore the value of energy demand as a final commodity (in monetary terms) that is already included in real *GRP* is counted twice. "Final" energy, however, accounts for a fairly small share of total value added, so the general usefulness of MACRO is not affected by this deficiency.

9. The notation used in this section should not be confused with that used in the other sections of the report. For instance, $Q$ is used to denote output here, rather than $y$ as in the other sections. This section constitutes a short survey of the theoretical foundation for the CES production function, and therefore somewhat different labels have been chosen to refer to given variables.

10. In this and the following equations the actual model will be presented. Therefore the labels may carry an additional term, such as $70, which indicates constant values measured in European Units of Accounts (EUA) at 1970 prices and exchange rates. Other variables are measured in current prices or physical units. Further information on variable units and the meaning of the mnemonics is given in Appendix A.

11. $a$ and $b$ do not necessarily add up to unity.

12. In the numerical specification of MACRO, the more exact variable total manhours worked *MH* was substituted for the more general variable labor.

13. One may also think of $p_K$ as the equivalent of an interest rate.

14. The following scenario parameters were incorporated into MACRO: $\eta_1$ reflects changes in indirect business taxes *TAXES* and $\eta_2$ reflects changes in income taxes *TAXDIR*; $\eta_3$ and $\eta_4$ allow adjustments in the export and import shares of GRP and thus permit manipulation of the trade balance.

15. See Appendix B for a discussion of data sources used in the modeling effort.

16. Exogenous variables are marked with an "x" or an "I" in the variable list provided in Appendix A.

17. MACRO's numerical analysis of the impact of the energy shock did not correspond in every respect to Fried and Schultze's qualitative description. For instance, reinvestment of the oil producing countries' surplus is not an option considered in MACRO, so the model cannot reflect the "transition phase" described by these analysts. As a consequence, crisis-induced losses in sales by consumption-goods industries could not be offset by exports to oil-producing countries in the model. To some degree, the fact that exports to other oil-importing countries were assumed to remain unaffected (although these countries faced similar slowdowns in economic activity and would have had to reduce their volume of imports) compensated for this model deficiency. The level of exports in the test case was assumed to correspond to the historically observed share of exports within the gross national product.

18. This rate was also assumed in the study conducted by the Commission of the European Communities (CEC 1980).

19. There is a sharp distinction between scenario variables and the scenario parameters. The former belong to the group of scenario-defining variables used in scenario writing, while the latter are used to impose necessary or desired changes within a defined scenario.

20. It is possible to circumvent the equilibrium condition by exogenously determining maximum labor supply. In this case, the model adjusts labor demand freely in accordance with the relative price structure of the other factors of production.

21. The energy demand calculations in "Crucial Choices for the Energy Transition" were carried out by the CEC's Directorate-General for Scientific and Technical Information and Information Management, using the MEDEE model.

22. A popular relationship, which combines income and price elasticities with respect to energy, is defined as follows:

$$\ln(E/E_0) = \lambda \ln(GRP/GRP_0) + \mu \ln(P/p_0)$$

where $\lambda$ is the energy–income elasticity, $\mu$ is the energy–price elasticity, and 0 is an index that determines the base year values for 1963 and 1979, respectively.

23. This is an extreme statement derived and interpreted from the simplistic concept of the interdependence of income and price elasticities. It is based on "back of an envelope" calculations.

24. In this context, historical trend denotes a continuation of the share of investments of the energy sector in total gross fixed capital formation observed between 1960 and 1976, i.e. 6.0–7.0%.

25. "Cost of capital" is the more exact term. It includes both interest and depreciation.

26. Some short-term diverging trends can be eliminated through the manipulation of certain scenario parameters (see Section 5.3).

27. Throughout the analysis presented in this report, the "elasticity of substitution" parameter was kept fixed at its estimated value of 0.38. Any value higher than 0.38 would decrease the energy–economy interdependence considerably, i.e., tighter energy availability would have less effect on economic growth rates. The uncertain validity of the constant elasticity assumption for the next 50 years – not to mention the uncertainty of its value in general – must be stressed.

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## APPENDIX A: DEFINITION OF VARIABLES

All variables included in MACRO are listed below. Endogenous variables are indicated by an "e" in the second column, exogenous ones by an "x". Variables that are inputs originating from other models within the IIASA set of energy models (and that therefore are exogenous to MACRO, but exogenous to the loop) are marked with an "l". For completeness, parameters mentioned in the text and variables used in the general model specification are also included in the list, indicated by a "p" and a "g", respectively. EUA stands for "European Units of Accounts" and ROE stands for "rest of the economy."

| VARIABLE | WHERE SPECIFIED | DEFINITION |
|---|---|---|
| $C_{\$70}$ | e | Personal consumption expenditures ($10^9$ EUA at 1970 prices and exchange rates) |
| $c(E)$ | g | Energy cost function for energy-exporting nations |
| $DEP$ | g | Consumption of fixed capital |
| $DEP_{\$70}$ | e | Consumption of fixed capital ($10^9$ EUA at 1970 prices and exchange rates) |

| | | |
|---|---|---|
| $E_{\text{index}}$ | l | Secondary energy demand ($10^6$ tce) |
| $E$ | l | Secondary energy demand index (1970 = 100) |
| $E^{\text{D}}$ | e | Domestic primary energy production ($10^6$ tce) |
| $E^{\text{D,R}}$ | e | Secondary energy demand in ROE ($10^6$ tce) |
| $E^{\text{E}}$ | l | Energy requirements within the energy sector ($10^6$ tce) |
| $E^{\text{I}}$ | e | Primary energy imports ($10^6$ tce) |
| $E^{\text{S}}$ | l | Secondary energy supply ($10^6$ tce) |
| $G_{\$70}$ | e | Government purchases of goods and services ($10^9$ EUA at 1970 prices and exchange rates) |
| $G(E^{\text{D}})$ | g | Domestic energy cost function |
| $GRP$ | g | Gross regional product |
| $GRP_{\$70}$ | e | Gross regional product ($10^9$ EUA at 1970 prices and exchange rates) |
| $GT$ | e | Government transfer payments to persons ($10^9$ EUA at 1970 prices and exchange rates) |
| $HOURS$ | x | Average total private nonagricultural hours of work per week |
| $INV$ | g | Gross fixed capital formation |
| $INV_{\$70}$ | e | Gross fixed capital formation ($10^9$ EUA at 1970 prices and exchange rates) |
| $INV^{\text{E}}_{\$70}$ | l | Supply of gross fixed capital formation in the energy sector ($10^9$ EUA at 1970 prices and exchange rates) |
| $INV^{\text{R}}_{\$70}$ | e | Supply of gross fixed capital formation in ROE ($10^9$ EUA at 1970 prices and exchange rates) |
| $INV^{\text{S}}_{\$70}$ | e | Total supply of gross fixed capital formation ($10^9$ EUA at 1970 prices and exchange rates) |
| $K$ | g | Capital stock at end of period |
| $K_{\$70}$ | e | Estimated capital stock at end of period ($10^9$ EUA at 1970 prices and exchange rates) |
| $K^{\text{D}}$ | g | Total demand for capital |
| $K^{\text{D,R}}_{\$70}$ | e | Capital stock required at end of period in ROE ($10^9$ EUA at 1970 prices and exchange rates) |
| $K^{\text{E}}_{\$70}$ | l | Capital stock at end of period in energy sector ($10^9$ EUA at 1970 prices and exchange rates) |
| $K^{\text{R}}_{\$70}$ | e | Supply of capital stock at end of period in ROE ($10^9$ EUA at 1970 prices and exchange rates) |
| $K^{\text{S}}$ | g | Total supply of capital |
| $L$ | g | Labor input |
| $L^{\text{S}}$ | e | Total labor force ($10^6$ persons) |
| $M$ | g | Imports of goods and services |
| $M_{\$70}$ | e | Imports of goods and services ($10^9$ EUA at 1970 prices and exchange rates) |
| $M^{\text{E}}_{\$70}$ | e | Energy imports ($10^9$ EUA at 1970 prices and exchange rates) |
| $M^{\text{N}}_{\$70}$ | e | Nonenergy imports ($10^9$ EUA at 1970 prices and exchange rates) |

| | | |
|---|---|---|
| $MH$ | e | Total manhours ($10^9$ hours) |
| $MH^{\mathrm{E}}$ | l | Annual demand for manhours in the energy sector ($10^9$ hours) |
| $MH^{\mathrm{R}}$ | e | Manhours worked in ROE |
| $MH^{\mathrm{R,D}}$ | e | Annual demand for manhours in ROE ($10^9$ hours) |
| $NI_{\$70}$ | e | National income ($10^9$ EUA at 1970 prices and exchange rates) |
| $p$ | e | Implicit price deflators for *GRP* (1970 = 100) |
| $p_E$ | l | Secondary energy price (EUA/tce) |
| $p_E^{\mathrm{index}}$ | l | Secondary energy price index (1970 = 100) |
| $p_I$ | l | Energy import price (EUA/tce) |
| $p_I^{\mathrm{index}}$ | l | Energy import price index (1970 = 100) |
| $p_{NEI}$ | x | Nonenergy import price index (1970 = 100) |
| $p_K$ | e | Real interest rate (cost of capital) (%) |
| $p_L$ | e | Wage rate (EUA at 1970 prices and exchange rates) |
| $p_M$ | e | Import price index (1970 = 100) |
| $p_V$ | x | Implicit price deflator of value added in ROE (1970 = 100) |
| $p_X$ | x | Export price index (1970 = 100) |
| $POP$ | x | Population |
| $POPOCC$ | e | Occupied population ($10^6$ persons) |
| $POP > 65$ | x | Population over 65 ($10^6$ persons) |
| $Q$ | g | Output (value added) |
| $R$ | g | Marginal rate of substitution |
| $RES$ | x | Residual from *GRP* identity ($10^9$ EUA at 1970 prices and exchange rates) |
| $SUR_{\$70}$ | e | Government budget, surplus or deficit ($10^9$ EUA at 1970 prices and exchange rates) |
| $TAXDIR$ | e | Personal taxes, corporation taxes, and social insurance ($10^9$ EUA at 1970 prices and exchange rates) |
| $TAXES$ | e | Indirect taxes and government surplus ($10^9$ EUA at 1970 prices and exchange rates) |
| $TB$ | e | Trade balance ($10^9$ EUA at 1970 prices and exchange rates) |
| $TIME$ | x | Time trend (1960 = 1) |
| $V$ | g | Value added in ROE |
| $V^{\mathrm{E}}$ | g | Value added in energy sector |
| $V_{\$70}$ | e | Value added in ROE ($10^9$ EUA at 1970 prices and exchange rates) |
| $V^{\mathrm{E}}_{\$70}$ | e | Value added in energy sector ($10^9$ EUA at 1970 prices and exchange rates) |
| $UNEMP$ | e | Unemployed persons ($10^9$ persons) |
| $w$ | g | Hourly wage rate |
| $X$ | g | Exports of goods and services |
| $X_{\$70}$ | e | Exports of goods and services ($10^9$ EUA at 1970 prices and exchange rates) |

| | | |
|---|---|---|
| $Y$ | g | Gross output of ROE |
| $Y_{\$70}$ | e | Gross output of ROE ($10^9$ EUA at 1970 prices and exchange rates) |
| $YD_{\$70}$ | e | Spendable income ($10^9$ EUA at 1970 prices and exchange rates) |
| $a$ | p | Distribution parameter for energy in the CES production function |
| $b$ | p | Distribution parameter for value added in the CES production fucntion |
| $c$ | p | Parameter |
| $r$ | p | Parameter |
| $cf$ | p | Conversion factor (primary to secondary energy) |
| $\alpha$ | p | Factor share of *GRP* to labor in Cobb–Douglas production function |
| $\beta$ | p | Substitution parameter in CES production function |
| $\gamma$ | p | Neutral productivity parameter in CES production function |
| $\epsilon_1$ | p | Energy price elasticity |
| $\delta$ | p | Distribution parameter in CES production function |
| $\delta^E$ | p | Consumption of capital in the energy sector |
| $\delta^R$ | p | Consumption of capital in ROE |
| $\eta_1$ | p | Scenario parameter for indirect taxes (*TAXES*) |
| $\eta_2$ | p | Scenario parameter for income taxes (*TAXDIR*) |
| $\eta_3$ | p | Scenario parameter for exports |
| $\eta_4$ | p | Scenario parameter for nonenergy imports |
| $\pi$ | p | Aggregate profit function of the ROE sector |
| $\pi_O$ | p | Energy-exporting countries' profit function for oil sales |
| $\sigma$ | p | Elasticity of substitution parameter in CES production function |
| $\theta$ | p | Productivity parameter in Cobb–Douglas production function |

## APPENDIX B: DATA SOURCES

The data for the 1960–1978 sample period originate mainly from publications of the Statistical Office of the European Communities (EUROSTAT 1972, 1976, 1977, 1978, 1979). Publications of individual national statistical offices of the EC member countries were also consulted when necessary. To maintain comparability and consistency, the aggregate, though sometimes incomplete[a] data series for the EC region as a whole were preferred to more precise data from national sources.

The European Community's "National Accounts ESA" publication (EUROSTAT 1977) provides primary macroeconomic accounts in aggregate form for the Community as a whole. The data contained in this publication include the components of aggregate demand and aggregate demographic information (population, labor force, employment, compensation of employed persons, for example). This source also contains aggregate time series on consumption of fixed capital, taxes linked to production (indirect taxes), national income, and price indices for gross regional product and its components. The post-1976 aggregates were derived from the indices provided by EUROSTAT (1979).

Data on direct taxes, social insurance contributions, government transfer payments to persons, as well as data on value added and capital formation related to the energy sector, were available only on a country-by-country basis in detailed tables within the EUROSTAT National Accounts series (EUROSTAT 1972, 1978). The necessary conversion of national data into real (constant) European Units of Accounts was based on 1970 exchange rates and prices. The aggregation of the national data would have been straightforward if compatible and complete time series for all nine EC member countries had been on hand. However, this was nearly never the case, except for the aggregated data provided in the national accounts statistics prepared by the European Communities (EUROSTAT 1977). The weighted-average method (still meeting minimum consistency requirements) was therefore used to make the aggregation in cases where the internal characteristics of an individual economy had to be taken into account, or when data were simply missing. Relevant relationships or postulated dependence on other existing aggregate variables were used to choose the weights. For example, the national income share of an individual country was used in determining missing data on direct taxes.

Data on energy consumption and energy imports were taken from the *Quarterly Bulletin of Energy Statistics* (EUROSTAT 1976), while energy prices were based both on the data for the Federal Republic of Germany, France, and the United Kingdom compiled by Doblin (1979) and on the data for Belgium, Italy, the Netherlands, and Luxembourg supplied by Cleutinx (1979). A unique energy price could be calculated from these data, using the weighted-average method.

The ILO *Bulletin of Labour Statistics* (1979) contains time series for the average hours worked per week in individual countries and data on the number of persons employed in the energy sector. In both cases, however the ILO statistics do not supply complete information. This made it necessary to consult national statistical publications and then to apply the weighted-average method, using the share of total occupied population as the identifier in the calculation of the employed persons in the energy sector.

One aggregate variable that proved difficult to construct was capital stock. Gross capital stock can be calculated using the following recursive permanent inventory equation:

$$K_t = K_{t-1} + INV_t - DEP_t$$

where $K_t$ is capital stock at the end of the present period, $K_{t-1}$ is capital stock at the end of the previous period, $INV_t$ is gross fixed capital formation at the end of the present period, and $DEP_t$ is consumption of fixed capital at the end of the present period. Data on investment and consumption of fixed capital stock were provided in the EUROSTAT statistics, but the use of this equation also required a value for the initial capital stock $K_0$ or an initial capital:output ratio. Unfortunately, data on capital stock were not provided at all in the EUROSTAT statistics and were available from national statistical publications on national accounts only for the Federal Republic of Germany, France, and the United Kingdom. It was therefore necessary to use in addition the aggregate capital-stock time series and capital: output ratios for Western Europe constructed by Ströbele (1975).

Applying the weighted-average method to the capital-stock information supplied by these sources, an initial (1970) capital:output ratio of 3.59 was calculated for the EC region. This value lies above Ströbele's aggregate value of 3.19 for Western Europe as a whole: but because the more industrialized countries of western Europe are concentrated in the EC region, the higher value of 3.59 seems reasonable.

## APPENDIX C: COMPUTERIZATION OF MACRO

The development of a macroeconomic model requires a computer system to handle various computation problems. As an unavoidable initial step, the modeler is confronted with the issue of data management. Appropriate time series, cross-sectional data and other information have to be collected and stored in a data bank. This data bank must be easily accessible at various points during the model's development process. The capability to manipulate and transform data, to add and easily retrieve information, and to provide adequate documentation is an essential requirement.

Once a data bank is established, it serves as a central tool in the succeeding steps of model development. These steps include estimation of econometric parameters and relationships, statistical analyses, and performance of significance tests for the estimated parameters. The data bank is accessed continuously, as data series are retrieved for the estimation procedure and the resulting information is stored.

The final step in the development of a macroeconomic model is the simultaneous solution of all estimated relationships. It is necessary to generate input files for the actual simulation, i.e., to provide the estimated coefficients and exogenously specified variables, before linear or nonlinear econometric models can be solved. Output files, graphs, and tables providing comparisons with reference cases complete model software requirements.

MACRO was designed and developed with the aid of the *Software Package for Economic Modeling*, created by Norman (1977). Although the software package was developed for the PDP 11/70 interactive mode of operation, it is almost computer-independent. Only slight modifications are needed to run the package on a CDC or IBM computer.

## APPENDIX D: FORTRAN SUBROUTINES

The subroutines *const.f, solve.f, and post.f* contain the necessary FORTRAN code for MACRO. These subroutines are compatible with SIM – the simulation component of the *Software Package for Economic Modeling* (Norman 1977). Each equation in MACRO is normalized for a different endogenous variable and is split into a constant component and a simulation component:

$$y(i) = f_i(y,z) + c(i)$$

where $y(i)$ is the $i^{\text{th}}$ endogenous variable, $f_i$ is the simulation component of the equation, $y$ is the vector of endogenous variables, $z$ is the vector of predetermined variables, and $c(i)$ is the constant component of the equation.

All predetermined (exogenous and lagged endogenous) variables should be coded in *const.f.* The development of productivity $y(26)$ is representative of the variables calculated in this subroutine. The actual nonlinear simulation part of the model is coded in *solve.f,* using the $c(i)$s calculated in *const.f*; an example is the determination of value added in the energy sector $y(49)$. In subroutine *solve.f,* the iterative process of a Gauss–Seidel algorithm is performed, and the subroutines *const.f* and *post.f* are called only once for each time step. After a converging solution has been obtained, SIM calls up subroutine *post.f.* Post-recursive equations are contained in this subroutine, i.e., equations that do not influence the solution of other endogenous equations, but depend on solution values from *solve.f* [e.g., the investment rate $y(13)$].

The subroutines *const.f, solve.f,* and *post.f* are presented below.

```
        SUBROUTINE CONST(y,ex,el)
       common i4,i5,i6,d(150),ia,a(100),i1,i2,pa,z(120),c(60),xnor(60)
    1     ,ibx(60),ca(60),inl(60),b(60),nv1,iy1,ip1,ib1,lab(61),ngr
    2     ,ik(60),test(60),logic(50),xl(65),sim,nvc,ned,nex,nxs,nl
    3     ,max,nt,ned1,nr,date1,date2,lis,title(12),ncol,nit,nvc1
    4     ,maxr,it(60),kset(60),nrr
      real*8 lab,ld,label
      integer date1,date2,error,sim,pa
      logical*1 logic,ltu,lfa
      dimension y(100),ex(100),el(100),tr(2)
c     exp(zzx)=zzx
      data ics/0/
      do 2 i=1,ned1
      xl(i)=-1.0e30
      if(inl(i).gt.0) xl(i)=x(1,i)
2     xnor(i)=1.0
      if(nxs.eq.1) go to 4
      do 3 i=1,nex
      el(i)=-1.0e30
      if(inl(i+ned).gt.0) el(i)=e(1,i)
3     ex(i)=z(i+ned)
4     continue
c
c     change of productivity over planning horizon
      if(z(38).gt.29.and.z(38).le.41.) a(4)=a(4)-.00113
      if(z(38).gt.41.) a(4)=a(4)-.0005
c
      y(26)=(exp(a(4)*z(38)+a(5)))*1.0103                   prod
      if(z(38).gt.29.) y(26)=exp(a(4)*3.)*xl(26)            prod
      if(z(38).eq.11.) y(59)=29.                            pr.dom
      if(z(38).gt.11.) y(59)=xl(59)*exp(a(55)*3.)           pr.dom
c
      if(z(38).le.17.) goto 44
      y(31)=xl(31)*exp(a(38)*3.)                            p-m.en
      if(z(38).gt.30.) a(38)=a(38)+a(39)                    p-m.en
c
44    c(21)=a(10)*(z(19)-z(20))+a(12)                       labor
      if(z(38).gt.17.) a(11)=a(11)+a(41)                    labor
      b(25)=z(24)*52./1000.                                 mh.tot
c
      if(z(38).gt.23.) a(28)=a(28)+a(44)                    m$.ne
      if(a(28).gt.a(40)) a(28)=a(40)                        m$.ne
      y(41)=a(17)*xl(45)+a(18)                              dep.re
      c(40)=a(37)*xl(40)                                    k$.en
      if(z(38).gt.17.) y(48)=a(36)                          p-k
      y(47)=xl(47)                                          p-l
c
      y(36)=z(33)*14.29*.001                                e.imp$
      y(57)=z(59)*z(54)*.001                                do.$df
      y(55)=z(36)*z(31)/z(28)                               m.e$df
      y(56)=z(55)/z(33)*1000.                               p-me$d
      y(60)=(z(55)+z(57))/z(12)*1000.                       dummy
      y(51)=z(60)*z(28)/100.                                p-en$
```

```
c
      a(21)=a(60)                                                       taxdir
c
      logic(2)=.true.
      logic(3)=.true.
      logic(4)=.true.
      logic(5)=.true.
c
      return
      end

      SUBROUTINE SOLVE(y,ex,el)
      common i4,i5,i6,d(150),ia,a(100),i1,i2,pa,z(120),c(60),xnor(60)
     1      ,ibx(60),ca(60),inl(60),b(60),nv1,iy1,ip1,ib1,lab(61),ngr
     2      ,ik(60),test(60),logic(50),xl(65),sim,nvc,ned,nex,nxs,nl
     3      ,max,nt,ned1,nr,date1,date2,lis,title(12),ncol,nit,nvc1
      real*8 lab,ld,label
      integer date1,date2,error,sim,pa
      logical*1 logic,ltu,lfa
      dimension y(100),ex(100),el(100)
c
1     nt=nt+1
c
      y(52)=((z(28)*.01*(z(1)-z(49))+z(34)*z(51)*.001)/(z(1)-z(49)+     gdp-df
     1z(34)*30.4*.001))*100.                                            gdp-df
c
      if(z(38).le.17.) goto 30
      dta=1.+(z(52)-xl(52))/xl(52)
      y(29)=xl(29)*dta                                                  p-x
      y(32)=xl(32)*dta                                                  p-m.ne
30    continue
c
c                          SUPPLY  SIDE
c
      y(21)=a(11)*z(47)+c(21)                                           labor
      y(25)=b(25)*z(21)                                                 mh.tot
      y(11)=z(25)-z(43)                                                 mhre.s
c
c       ITERATIONS' SECTION
c
      if(z(46).gt.z(11).or.z(11).gt.1.05*z(46)) logic(2)=.false.        mh.it
      if(z(46).gt.z(11)) y(47)=1.02*z(47)                               mh.it
      if(z(11).gt.1.07*z(46)) y(47)=.99*z(47)                           mh.it
c
      if(z(34).gt.z(12)) y(51)=1.01*z(51)                               ene.it
      if(z(12).gt.1.01*z(34)) y(51)=.99*z(51)                           ene.it
c
      y(58)=z(51)/z(52)*100.                                            p-e.s$
      b(60)=z(60)-z(58)                                                 diff
c
      if(z(45).gt.z(10)) y(48)=1.01*z(48)                               k.it
      if(z(10).gt.1.01*z(45)) y(48)=.99*z(48)                           k.it
c
c
      y(3)=a(13)*z(1)+a(14)*z(39)+a(15)*z(48)+a(16)                     Inv$
      y(44)=z(3)-z(37)                                                  I$.re
      y(10)=xl(10)+3.*(z(44)-z(41))                                     K$re.s
c
c       CES-function
c
      y(42)=(a(2)*z(12)**(-a(1))+a(3)*(z(26)*z(10)**(1.-a(6))           Y$
     1*z(46)**a(6))**(-a(1)))**(-1./a(1))                               Y$
c
c
c                                 DEMAND  SIDE
c
      r0=z(48)*.01*z(42)**(-a(1)-1.)*z(26)**a(1)/(a(3)*                 gk$.d
     1(1.-a(6)))*z(46)**(a(1)*a(6))                                     gk$.d
      y(45)=r0**(1./(a(1)*a(6)-a(1)-1.))                                gK$.d
c
      t0=z(47)*z(42)**(-a(1)-1.)*z(26)**a(1)/(a(3)*a(6))                mhre.d
     1*z(45)**(a(1)-a(1)*a(6))                                          mhre.d
      y(46)=t0**(-1./(a(1)*a(6)+1.))                                    mhre.d
```

```
c
      ye=.001*z(51)/(z(52)*.01)/a(2)                                        sec.de
      y(34)=ye**(1./(-a(1)-1.))*z(42)                                       sec.de
c
c               TAXES, etc.
c
      y(16)=a(19)*z(52)*z(1)*.01+a(20)                                      taxin
      y(17)=a(21)*z(52)*z(8)*.01+a(22)                                      taxdir
      y(15)=z(2)/z(19)                                                      c/pop
      y(18)=a(23)*(z(20)+z(23))+a(24)*z(15)*z(52)*.01+a(25)                 gtr
c
c       IDENTITIES
c
      y(1)=z(42)-z(58)*z(12)*.001+z(49)                                     grp$
      y(7)=z(45)+z(40)                                                      gk$
      y(8)=z(1)-z(41)-c(40)-z(16)/z(52)*100.                                ni$
      y(9)=z(8)-(z(17)-z(18))/z(52)*100.                                    yd$
      y(2)=a(42)*z(9)+a(43)                                                 c$
      if(z(38).gt.23.) y(2)=z(9)-z(3)+z(41)+c(40)                           c$
c
c       TRADE
c
      y(5)=(a(26)*z(1)*z(52)*.01+a(27))/(z(29)*.01)                         x$
      y(35)=(a(28)*z(1)*z(52)*.01+a(29))/(z(32)*.01)                        m.ne$
      y(6)=z(35)+z(36)                                                      m$
      y(39)=z(5)-z(30)/z(29)*z(6)                                           tb
c
c               Miscellaneous
c
      c(7)=a(54)*z(7)                                                       K$.en
      y(40)=3.*z(37)+xl(40)-3.*c(40)                                        K$.en
      if(c(7).gt.z(40)) logic(3)=.false.                                    K$.en
      if(.not.logic(3)) y(37)=(c(7)-a(54)*xl(7))/3.+c(40)                   inv.en
      if(.not.logic(3)) y(40)=3.*z(37)+xl(40)-3.*c(40)                      K$.en
      y(49)=z(47)*z(43)+c(7)*z(48)*.01                                      va$.en
      y(50)=z(40)-c(7)                                                      adj.Ke
c
      y(22)=z(21)-z(23)                                                     ocpop
      y(23)=(z(11)-z(46))*1000./(52.*z(24))                                 unempl
      y(4)=z(1)-z(2)-z(3)-z(5)+z(6)-b(37)                                   g$
      if(logic(2)) y(47)=z(1)*(1.-a(6))/(z(46)+z(43))                       w*
      y(30)=(z(35)*z(32)+z(36)*z(31))/(z(35)+z(36))                         p-m
      if(.not.logic(5)) goto 31                                             d-in.e
      b(37)=z(37)-.08*z(3)                                                  d-in.e
      if(b(37).gt.0.) logic(4)=.false.                                      d-in.e
      if(.not.logic(4)) a(58)=a(21)+a(59)                                   d-in.e
      if(.not.logic(4)) tt1=b(37)*z(52)/100.                                d-in.e
      if(.not.logic(4)) tt2=tt1-(a(58)-a(60))*z(52)*z(8)*.01+a(22)          d-in.e
      if(.not.logic(4)) a(21)=a(58)                                         taxdir
      if(tt2.le.0.) logic(5)=.false.
31    logic(4)=.true.
c
      if (nt.lt.nit) go to 1
      return
      end

      SUBROUTINE POST(y,ex,el)
      common i4,i5,i6,d(150),ia,a(100),i1,i2,pa,z(120),c(60),xnor(60)
     1      ,ibx(60),ca(60),inl(60),b(60),nv1,iy1,ip1,ib1,lab(61),ngr
     2      ,ik(60),test(60),logic(50),xl(65),sim,nvc,ned,nex,nxs,nl
     3      ,max,nt,ned1,nr,date1,date2,lis,title(12),ncol,nit,nvc1
      real*8 lab,ld,label
       integer date1,date2,error,sim,pa
      logical*1 logic,ltu,lfa
      dimension y(100),ex(100),el(100)
c
      y(27)=((z(16)+z(17)-z(4)*.01*z(52)-z(18)))/(z(52)*.01)                surplus
      y(3)=z(3)+b(37)                                                       inv$.a
      y(13)=z(3)/z(1)                                                       i/gnp
      y(14)=z(2)/z(1)                                                       c/gnp
c
      if(sim.ne.2) goto 1
1     return
      end
```

The Fortran routines contain coefficients and numbered variables. The corresponding variable names and the coefficients' values are given below.

a vector

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.5754 | 2 | 0.0671 | 3 | 0.8970 | 4 | 0.0295 | 5 | −0.1542 |
| 6 | 0.6606 | 7 | 0.0000 | 8 | 0.6724 | 9 | 31.9003 | 10 | −0.3016 |
| 11 | 7.7450 | 12 | 159.7051 | 13 | 0.1763 | 14 | 0.7058 | 15 | 13.7946 |
| 16 | −106.1501 | 17 | 0.0424 | 18 | −28.6982 | 19 | 0.1062 | 20 | 16.9305 |
| 21 | 0.3311 | 22 | −14.0093 | 23 | 2.6369 | 24 | 82.1011 | 25 | −87.3376 |
| 26 | 0.2950 | 27 | −0.2471 | 28 | 0.2394 | 29 | −25.8946 | 30 | 0.9092 |
| 31 | 0.0470 | 32 | 0.8107 | 33 | 0.1456 | 34 | 0.6577 | 35 | 0.0232 |
| 36 | 9.4000 | 37 | 0.0300 | 38 | 0.1000 | 39 | −0.0050 | 40 | 0.2750 |
| 41 | −0.3000 | 42 | 0.8357 | 43 | −1.1792 | 44 | 0.0016 | 45 | 0.6000 |
| 46 | −0.0083 | 47 | 0.0210 | 48 | 0.0125 | 49 | −0.0008 | 50 | 0.0244 |
| 51 | 0.0010 | 52 | −0.0050 | 53 | 0.1000 | 54 | 0.0703 | 55 | 0.0300 |
| 56 | −0.0011 | 57 | −0.0005 | 58 | 0.0000 | 59 | 0.0010 | 60 | 0.3311 |
| 61 | 0.0000 | 62 | 0.0020 | 63 | 0.2950 | | | | |

| num | name | test | kset | lag | ibx | no | iy | ip | ib |
|---|---|---|---|---|---|---|---|---|---|
| 1 e | grp$70 | 0.010 | 1 | 1 | 1 | 6 | 0 | 1 | 1 |
| 2 e | c$70 | 0.010 | 2 | 0 | 3 | 6 | 0 | 1 | 1 |
| 3 e | inv$70 | 0.010 | 3 | 0 | 4 | 6 | 0 | 1 | 1 |
| 4 e | g$70 | 0.010 | 4 | 0 | 5 | 6 | 0 | 1 | 1 |
| 5 e | x$70 | 0.010 | 5 | 0 | 6 | 6 | 0 | 1 | 1 |
| 6 e | m$70g | 0.010 | 6 | 0 | 7 | 6 | 0 | 1 | 1 |
| 7 e | gk$70 | 0.010 | 7 | 1 | 8 | 6 | 0 | 1 | 1 |
| 8 e | ni$70 | 0.010 | 8 | 0 | 10 | 6 | 0 | 1 | 1 |
| 9 e | yd$70 | 0.010 | 9 | 0 | 11 | 6 | 0 | 1 | 1 |
| 10 e | gk$re.s | 0.010 | 10 | 1 | 12 | 1 | 2 | 1 | 1 |
| 11 e | mhre.s | 0.010 | 11 | 0 | 14 | 1 | 0 | 1 | 1 |
| 12 x | sec.sup | 0.010 | 12 | 1 | 15 | 6 | 0 | 1 | 1 |
| 13 e | i/grp | 0.010 | 13 | 0 | 17 | 6 | 0 | 1 | 1 |
| 14 e | c/grp | 0.010 | 14 | 0 | 18 | 6 | 0 | 1 | 1 |
| 15 e | c/pop | 0.010 | 15 | 0 | 19 | 6 | 0 | 1 | 1 |
| 16 e | taxin | 0.010 | 16 | 0 | 20 | 6 | 0 | 1 | 1 |
| 17 e | taxdir | 0.010 | 17 | 0 | 21 | 6 | 0 | 1 | 1 |
| 18 e | gtr | 0.010 | 18 | 0 | 22 | 6 | 0 | 1 | 1 |
| 19 x | pop | 0.010 | 19 | 0 | 23 | 24 | 0 | 1 | 1 |
| 20 x | pop>65 | 0.010 | 20 | 0 | 24 | 24 | 0 | 1 | 1 |
| 21 x | labor | 0.010 | 21 | 0 | 25 | 6 | 0 | 1 | 1 |
| 22 e | ocpop | 0.010 | 22 | 0 | 26 | 6 | 0 | 1 | 1 |
| 23 e | unempl | 0.010 | 23 | 0 | 27 | 6 | 0 | 1 | 1 |
| 24 x | hours/w | 0.010 | 24 | 0 | 28 | 22 | 2 | 1 | 1 |
| 25 e | mh.tot | 0.010 | 25 | 1 | 29 | 4 | 2 | 1 | 1 |
| 26 e | prod | 0.010 | 26 | 1 | 31 | 1 | 0 | 1 | 1 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 27 e | surpl | 0.010 | 27 | 0 | 33 | 1 | 0 | 1 | 1 |
| 28 x | p-va | 0.010 | 28 | 1 | 34 | 24 | 0 | 1 | 1 |
| 29 x | p-x | 0.010 | 29 | 1 | 36 | 6 | 0 | 1 | 1 |
| 30 e | p-m | 0.010 | 30 | 0 | 38 | 6 | 0 | 1 | 1 |
| 31 x | p-m.en | 0.010 | 31 | 1 | 39 | 6 | 0 | 1 | 1 |
| 32 x | p-m.ne | 0.010 | 32 | 1 | 41 | 6 | 0 | 1 | 1 |
| 33 x | m-en | 0.010 | 33 | 1 | 43 | 24 | 0 | 1 | 1 |
| 34 e | sec.dem | 0.010 | 34 | 1 | 45 | 6 | 0 | 1 | 1 |
| 35 e | m$70-ne | 0.010 | 35 | 0 | 47 | 6 | 0 | 1 | 1 |
| 36 e | m$70-en | 0.010 | 36 | 0 | 48 | 1 | 0 | 1 | 1 |
| 37 x | inv$.en | 0.010 | 37 | 1 | 49 | 6 | 0 | 1 | 1 |
| 38 x | time | 0.010 | 38 | 0 | 51 | 24 | 0 | 1 | 1 |
| 39 e | eb | 0.010 | 39 | 0 | 52 | 6 | 0 | 1 | 1 |
| 40 e | k$.en | 0.010 | 40 | 1 | 53 | 6 | 0 | 1 | 1 |
| 41 e | dep$.re | 0.010 | 41 | 0 | 55 | 6 | 0 | 1 | 1 |
| 42 e | y$70 | 0.010 | 42 | 0 | 56 | 5 | 1 | 1 | 1 |
| 43 e | mh.en | 0.010 | 43 | 1 | 57 | 4 | 2 | 1 | 1 |
| 44 e | inv$.re | 0.010 | 44 | 0 | 59 | 6 | 0 | 1 | 1 |
| 45 e | gk$.re | 0.010 | 45 | 1 | 60 | 6 | 0 | 1 | 1 |
| 46 e | mhre.d | 0.010 | 46 | 0 | 62 | 4 | 2 | 1 | 1 |
| 47 e | w-rate/p | 0.010 | 47 | 1 | 63 | 4 | 2 | 1 | 1 |
| 48 e | r/p | 0.010 | 48 | 1 | 65 | 22 | 2 | 1 | 1 |
| 49 e | va$.en | 0.010 | 49 | 1 | 67 | 6 | 0 | 1 | 1 |
| 50 x | adj.ke | 0.010 | 50 | 1 | 69 | 1 | 0 | 1 | 1 |
| 51 x | p-en$ | 0.010 | 51 | 1 | 71 | 23 | 1 | 1 | 1 |
| 52 e | grp-def | 0.010 | 52 | 1 | 73 | 7 | 0 | 1 | 1 |
| 53 x | prim.en | 0.010 | 53 | 1 | 75 | 24 | 0 | 1 | 1 |
| 54 x | dom.en | 0.010 | 54 | 1 | 77 | 6 | 0 | 1 | 1 |
| 55 x | m$-e.df | 0.010 | 55 | 1 | 79 | 6 | 0 | 1 | 1 |
| 56 x | p-e.m$df | 0.010 | 56 | 1 | 81 | 1 | 0 | 1 | 1 |
| 57 x | do.e$df | 0.010 | 57 | 1 | 83 | 1 | 0 | 1 | 1 |
| 58 x | p-e.s$df | 0.010 | 58 | 1 | 85 | 1 | 0 | 1 | 1 |
| 59 x | p-e.do$d | 0.010 | 59 | 1 | 87 | 1 | 0 | 1 | 1 |
| 60 x | dummy | 0.010 | 60 | 1 | 89 | 1 | 0 | 1 | 1 |

## NOTE TO THE APPENDIXES

*a* Denmark, Ireland, and the United Kingdom joined the EC after 1960.

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# EVOLUTION OF FUTURE ENERGY DEMAND TILL 2030 IN DIFFERENT WORLD REGIONS: AN ASSESSMENT MADE FOR THE TWO IIASA SCENARIOS

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## SUMMARY

*This report describes the essential features and the results of a final energy demand assessment made at the International Institute for Applied Systems Analysis (IIASA), covering six of the seven world regions considered in the recently completed global study of IIASA's Energy Systems Program. The assessment was made using the scenario-development approach embodied in a model called MEDEE-2 that was adopted at IIASA for projecting the medium- to long-term energy demand at the level of world regions. This approach first analyzes the base year energy demand for different sectors in a region in terms of useful/final energy requirements for a large number of activities in each sector, and then projects this demand for later periods by identifying the plausible evolution of various socioeconomic activities and by estimating the probable technological improvements and lifestyle changes in the coming decades.*

*The starting point for the assessment was a set of basic scenario assumptions concerning population growth and economic development (measured in terms of GDP growth). Two different scenarios were analyzed: they are labelled High and Low with respect to two different sets of assumptions implying relatively high and relatively low economic growth rates. They cover a plausible range of values for world economic growth during the next 50 years. The population growth rate assumptions are common to both the scenarios.*

*This assessment involved estimating the base year (1975) values of some 180 parameters for each region and projection of the values of these parameters to the years 2000 and 2030 in a manner consistent with the basic scenario assumptions, while incorporating feasible technological improvements and plausible lifestyle changes. The report lists the estimated base year values of the various parameters, describes how they were estimated, and gives sources of information. Similarly, it lists the projected values of these parameters, and describes the underlying reasoning. Finally, it discusses the requirements of final energy for various sectoral activities and the extent of conservation incorporated in the projections.*

*Some of the main results of this assessment are:*

*1. By 2030 the final energy demand in the developed regions (IIASA Regions I – North America; II – The Soviet Union and Eastern Europe, and III – Western Europe, Japan, Australia etc.) will increase by a factor of 1.8 to 2.6 as compared to that in 1975, whereas that in the three developing regions considered in the present assessment (i.e., IIASA Regions IV – Latin America; V – Africa, except Northern Africa and South Africa, and South East Asia, and VI – Middle East and Northern Africa) will increase by a factor of 7 to 12. The projected demand in the various regions will, however, be lower than that estimated on the basis of historical final energy-to-GDP elasticity of each region by 16 percent to 40 percent in the Low scenario and 23 percent to 54 percent in the High scenario.*

*2. The per capita final energy consumption in the developed regions I, II, and III will increase from a level of 2.8–7.9 kW in 1975 to a level of 3.9–11.6 kW by 2030, whereas that in the developing regions IV, V, and VI will increase from 0.2–0.8 kW to 0.5–4.6 kW over the same period. Among the developing regions the largest increase will occur in the resource-rich Region VI and the smallest increase will occur in the resource-poor Region V.*

*3. The sectoral shares of final energy demand in various world regions will not undergo major changes during the next 50 years, so that the regional differences in the sectoral distribution of final energy will persist. In particular, the transportation sector in the developing regions and the household/service sector in the developed regions will continue to have relatively higher shares in the final energy demand than those commanded by the corresponding sectors in other regions.*

*4. The share of electricity in final energy will increase everywhere – from 10–13 percent in 1975 to 20–23 percent in 2030 in the developed regions, and from 4–10 percent in 1975 to 15–17 percent in 2030 in the developing regions.*

*5. The specific liquid fuel requirements as motor fuel or petrochemical feedstocks will, in 2030, account for a 34 percent to 43 percent share of final energy in the developed regions and 45 percent to 57 percent in the developing regions. The corresponding shares in 1975 in the developed and the developing regions are in the range of 24–37 percent and 32–52 percent respectively.*

*6. Manufacturing activities will continue to dominate the industrial final energy demand (i.e., the demand from the manufacturing, mining, agriculture, and construction sectors) in all regions. The share of manufacturing in the industrial final energy demand in 2030 for different regions will be in the range of 76–90 percent, as compared to 62–92 percent in 1975.*

*7. The automobile share of transportation energy demand will decrease in the developed regions and increase in the developing regions. The most notable change will occur in Region I, where this share will decline from 67 percent in 1975 to 19–29 percent in 2030. The automobile share in the transportation sector's final energy demand for different regions will lie in the range of 8–36 percent in 2030, as against 6–67 percent in 1975.*

*8. In 2030 soft solar devices will be able to meet about 1–3 percent of the useful thermal energy requirements of the manufacturing sector and 5–13 percent of those of the household/service sector in the developed regions. The corresponding shares in the developing regions will be in the ranges of 4–5 percent and 2–12 percent, respectively.*

*9. In spite of gradually increasing penetration of electricity, heat pumps, soft solar, and district heat in the heat markets of the manufacturing and household/service sectors, fossil fuels will continue to be the most important source of thermal energy in these sectors in all regions except Region II. In 2030 the shares of substitutable fossil fuels (i.e., fossil fuels for thermal uses) in developed Regions I and III and the developing regions will be in the range 80–90 percent for the manufacturing sector and 55–85 percent for the household/service sector. The corresponding shares in Region II will be about 30 and 25 percent, respectively, due to continued heavy reliance on district heating systems in this region*

## 1 INTRODUCTION

IIASA's Energy Systems Program deals with the medium- to long-term aspects of global energy supply and demand. It concentrates on a period of 15–50 years from now, during which the world energy system will have to undergo a major transition. This transition will result from a large increase in world population, the expected industrialization and relatively fast economic growth of the developing countries, and the worldwide scarcity of the hitherto cheap conventional forms of energy, particularly of conventional oil and natural gas. The major findings of this study have recently been reported in *Energy in a Finite World: A Global Systems Analysis* (Energy Systems Program Group 1981).

This current report gives an assessment of final energy demand in various world regions that was carried out as a part of the above program by using an energy demand model called MEDEE-2.

For the purpose of IIASA's energy systems study, the world was divided into seven regions, as illustrated in Figure 1. (For a complete listing of the countries in each region see Appendix A.) The grouping of countries in these regions was based not on their geographical proximity but on considerations of similarities in social, economic, and demographic structures, and on prospects of economic growth and availability of energy resources. The work described in this report covers only the first six of the seven world regions shown in Figure 1. The energy demand assessment for Region VII (China and Centrally Planned Asian Economies) was not carried out with MEDEE-2 due to the lack of data. A simplified model called SIMCRED (Parikh 1978) was used for this region; this report does not discuss the assessment nor results.

The long-term projection of energy demand and supply in various world regions can be made only in the light of mutually consistent projections of population, economic growth, availability of energy, material, and other resources, some perception of technological innovation and development, and in the wake of various physical, social, and environmental constraints. In order to obtain a consistent picture, one has to look at all these factors both individually and collectively, and through an iterative procedure try to eliminate internal inconsistencies.

Such an analysis was carried out at IIASA using a set of mathematical models as the major analytical tool (Basile 1980). The flow of information between these models is schematically shown in Figure 2. It begins with some initial scenario definitions of the economic and population growth rates in the various world regions. The demand of final energy in each region is then evaluated with the energy demand model MEDEE-2 projecting

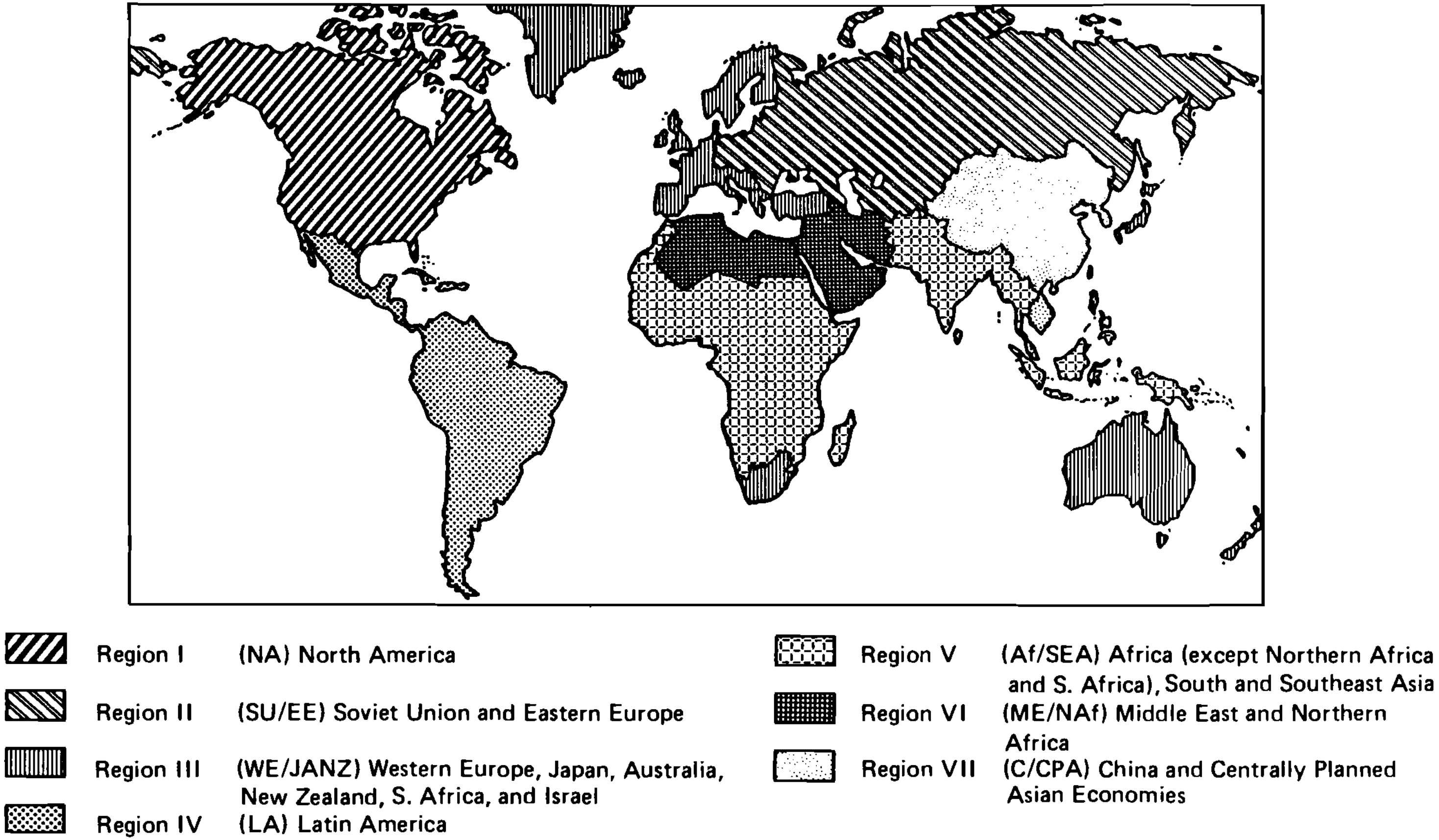

FIGURE 1 The IIASA world regions.

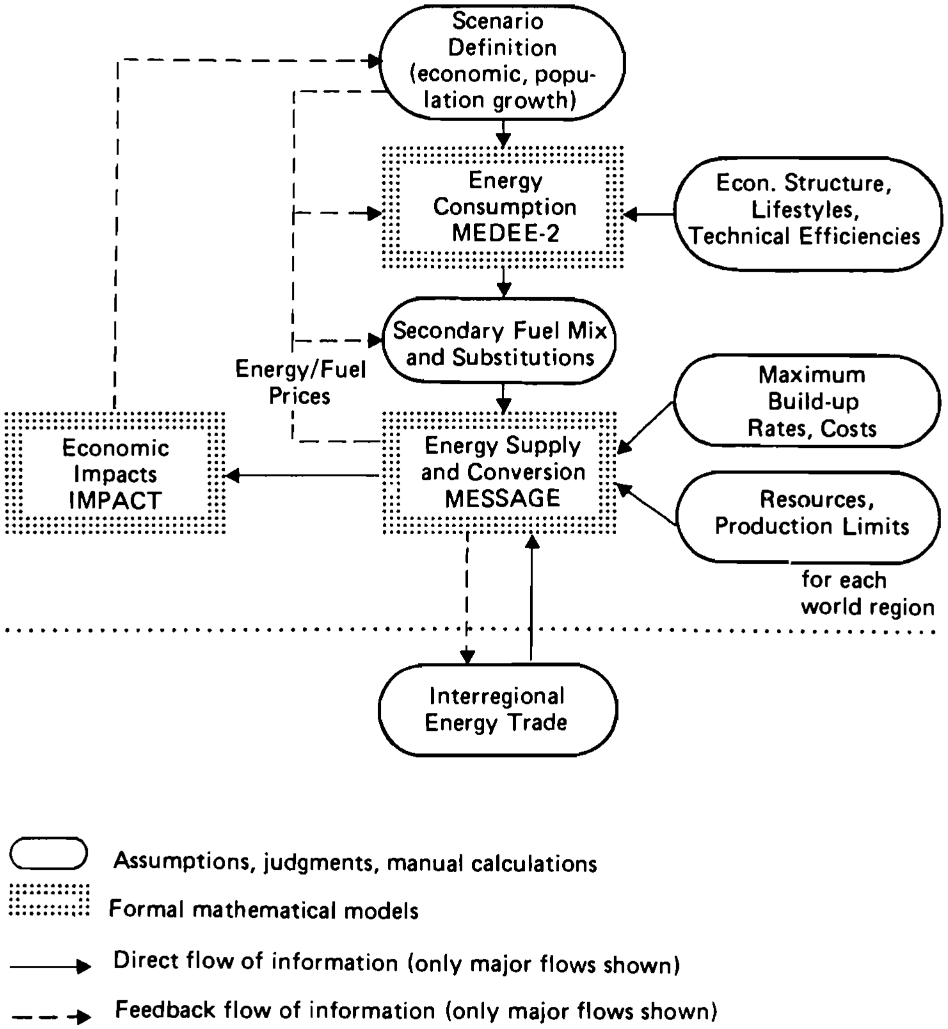

FIGURE 2 IIASA's set of energy models: a simplified representation.

changes in economic structure, lifestyles, technical efficiencies, etc., that could be expected under the basic scenario conditions. The energy supply model MESSAGE then calculates optimal supply strategies consistent with the availability of energy resources and subject to various constraints encompassing technological, environmental, and other related issues. Consideration of the interregional energy trade calls for iteration of the MESSAGE runs for various regions until a globally consistent picture emerges. The economic impacts of the regional supply strategies are then analyzed in the energy–economy interaction model IMPACT. The corresponding implications and the estimates of energy and fuel prices, obtained from the MESSAGE runs, are used to modify – if necessary – the scenario definitions of regional economic growth and the projections of some of the parameters used in the MEDEE-2 runs of the preceding iteration of the modeling loop. This procedure is repeated until the demand and supply projections are considered to be "reasonable" and consistent.

This report is concerned mainly with the assessment of final energy demand, based on a MEDEE-2 analysis, for the IIASA Regions I through VI. In order to provide a proper appreciation of the assessment procedure, we also briefly describe the energy accounting and the analytical approach used in the MEDEE-2 analysis. (A formal description is given in Appendix B.) A description follows of the input data actually used for the base year (1975), of the values assigned to the scenario variables for the years 2000 and 2030 in the various world regions, and of the underlying assumptions. The results of the MEDEE-2 analysis are then discussed in terms of the projected energy requirements for various sectoral activities and the extent of "conservation" incorporated in these projections.

## 2 SOME DEFINITIONS

In discussing the issues related to energy demand and supply, a distinction must be made between the different forms of energy usually referred to as primary energy, secondary energy, final energy, and useful energy. The difference between these various forms is illustrated in Figure 3.

*Primary energy** represents the energy content of extracted raw fuels, e.g., crude oil or natural gas at the wellhead, coal at the minemouth. Some primary fuels need to be refined or converted to secondary energy, in oil refineries or power plants, with typically rather large conversion losses (at least 60 percent losses in the case of coal converted to electricity); others can be transported and used directly as secondary energy.

*Secondary energy*, after transmission and distribution through major networks (e.g., oil/gas pipelines, delivery trucks, high and low voltage lines), becomes final energy. Electricity at the output, or busbar, of a power station is secondary energy; electricity at the home wallplug is final energy.

*Final energy* is energy delivered to final consumers – oil delivered to burners in the basement, or to industrial boilers. Final energy is what the consumer buys.

*Useful energy* is what one actually benefits from – the heat that warms living rooms, for example. Produced photons, heated air, kinetic energy are useful energy. All conversion processes from primary energy through useful energy involve varying amounts of losses due to conversion and/or transmission, storage, and distribution (see Figure 3). After providing the required energy services, in combination with other inputs such as capital, know-how, and labor, the useful energy is ultimately rejected to the environment. The amount of useful energy needed to obtain a given amount of energy services depends

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*Primary energy also includes fossil fuel equivalents, for example, of nuclear energy and hydropower converted to electricity; and the energy obtained from new sources such as solar, geothermal, wind, ocean thermal gradients, charcoal and fuelwood from forests, planned wood plantations, biogas, etc. Except where indicated, primary energy excludes noncommercial use of fuels such as firewood, farm wastes, and animal wastes.

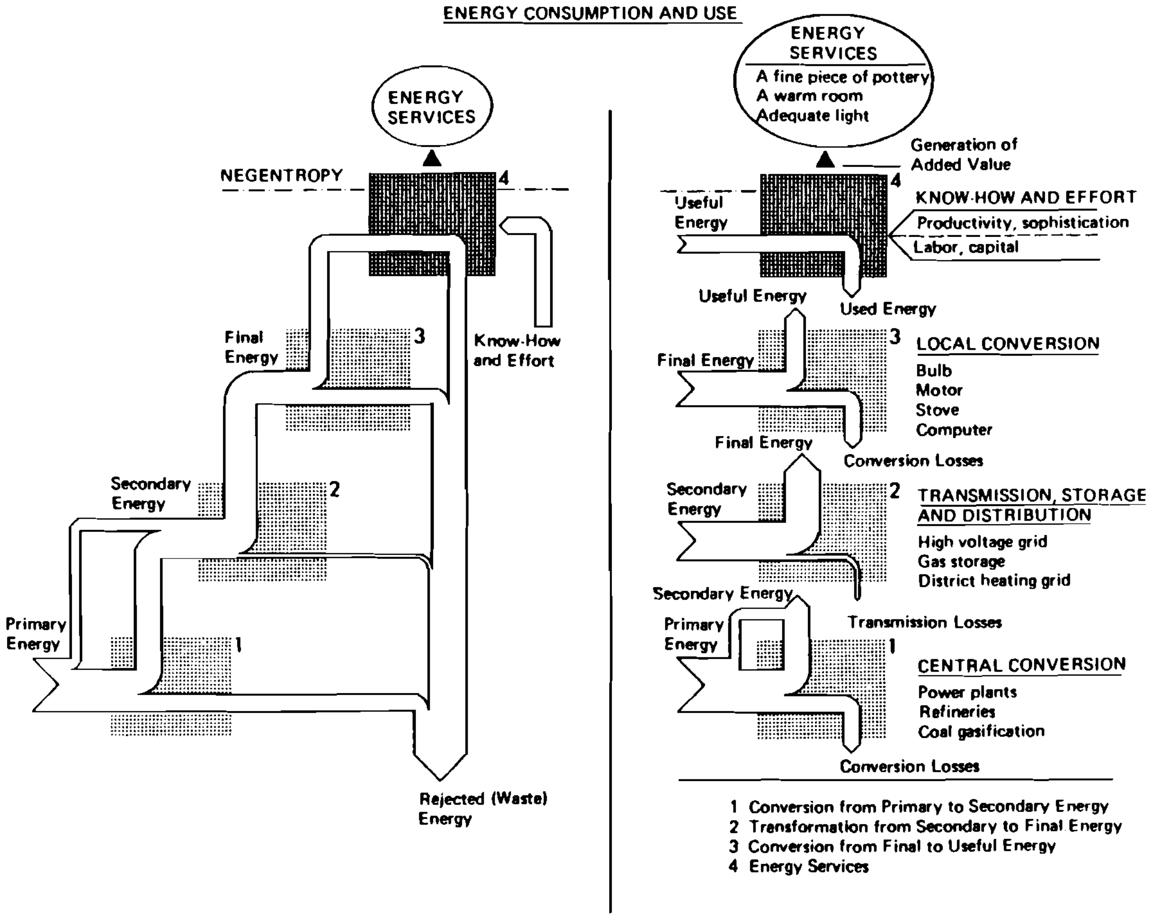

FIGURE 3 Energy conversion and use.

on the relative magnitudes of these other inputs (Häfele 1977), and this leads to the ultimate potential of energy conservation.

The energy demand projections discussed in this report were made only in terms of useful and/or final energy forms. The evaluation of secondary and primary energy requirements, based on these demand projections, was made in the MESSAGE model runs and has been described in Energy Systems Program Group (1981).

## 3 THE MEDEE-2 MODEL FOR ENERGY DEMAND ASSESSMENT

### 3.1 Methodological Approach

MEDEE-2 is a simulation model for evaluating the energy demand implications of a scenario describing a hypothetical evolution of economic activities, changes in the lifestyle of the population, and technological improvements.* It is based on a disaggregation of total energy demand into a multitude of end-use categories – such as heating or cooling of dwellings, passenger transportation by mode, or steam generation in industry. For thermal uses of energy, where the useful energy demand can be provided by various enery sources (e.g., fossil fuels, district heat, electricity, or solar systems), the energy demand is calculated first in terms of useful energy** and then converted to final energy terms based on assumptions about the penetration of various energy sources into their potential end-use markets and about their end-use efficiency. For all other energy use categories, such as motor fuel for automobiles or electricity for electrolysis, lighting, various household appliances, etc., the energy demand is directly calculated in final energy terms, they are called "nonsubstitutable uses," in the sense that substitutions would be difficult and are therefore unlikely.

For each end-use category, energy demand (useful or final) is related to a set of determining factors, which may be macroeconomic aggregates, physical quantities, or technological coefficients. The energy demand projections result from the evolution assumed for these factors. Because of this high level of disaggregation and the relatively few structural assumptions built into the model, it can be viewed as an *accounting framework* of the energy uses in a country or a region.

Figure 4 shows the scheme for projecting useful and/or final energy demand used in MEDEE-2. The starting point is a scenario that defines an environment of population growth, economic development, energy availability, and prices envisaged for the future. These general scenario parameters must be disaggregated in terms of economic structure, demographic structure and lifestyles, and technological structure. Various elements make up these factors – gross domestic product (GDP) expenditure and formation and production of certain energy intensive basic industry products, labor force participation, urban/rural

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*MEDEE-2 is a simplified version of a more general approach developed by Chateau and Lapillonne (1977) at the Institute des Etudes Juridiques et Economiques, University of Grenoble, France. It was adapted by Lapillonne (1978a) for the global energy demand assessment in IIASA's Energy Systems Program. In the course of the study, several changes were made to the program. The main equations and variable definitions corresponding to the present state of the model are listed in Appendix B. It may also help to understand how the various parameters affect the results, and dispel ambiguities about the scope.

**For this assessment, useful energy for thermal processes is expressed as equivalent requirements of electricity. This implies that all efficiencies are specified relative to the efficiencies of electricity.

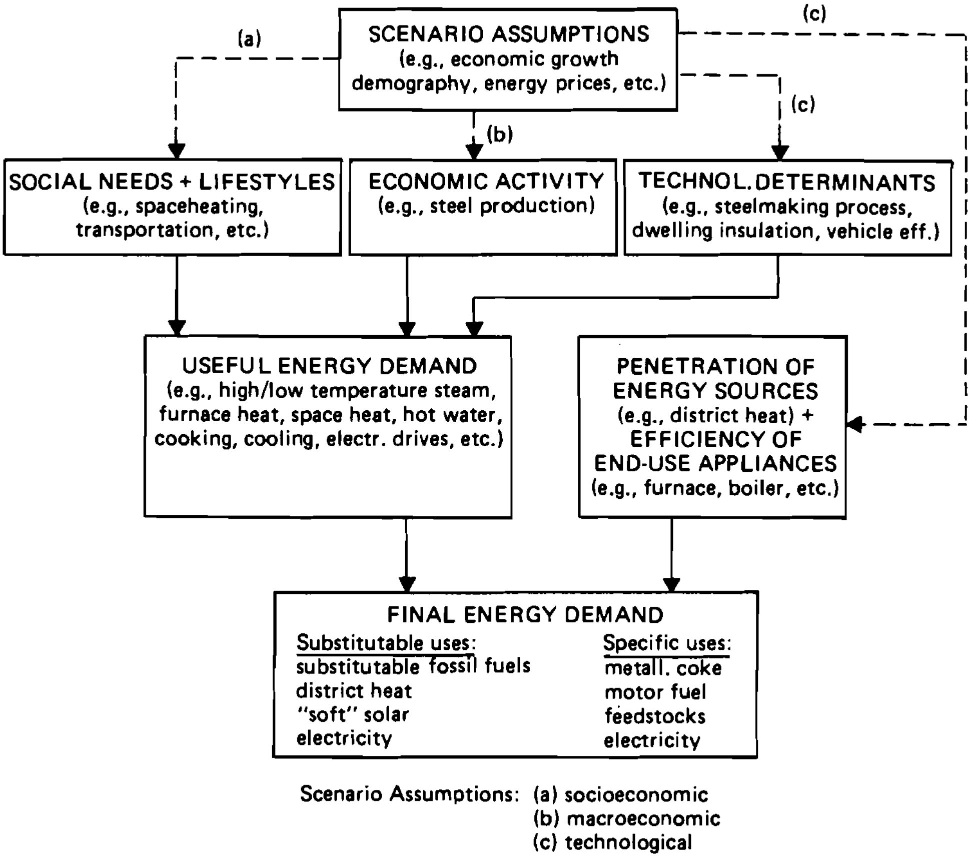

FIGURE 4 Schematic description of MEDEE-2.

split, household size, type and size of dwellings, energy-using equipment, travel distances, automobile ownership, preferences for certain modes of travel, energy intensity of industrial sectors, dwelling insulation, fuel economy of vehicles and many others.

Each of the factors mentioned would merit detailed investigation, or at least a survey of relevant studies. The fact that the various assumptions – though not formally interrelated in MEDEE-2 – are not independent from each other, raises the question of consistency. For example, energy prices are only judgmentally incorporated into the model; import–export relations are not explicitly treated (for small countries, trade of energy-intensive products can have a significant influence on the average energy intensity, but the effect will be small on the level of world regions considered in this study); the relation between lifestyle changes and purchasing power is not formalized; the relation between economic growth and turnover of capital stock is not modeled. All these factors enter only judgmentally, where one assigns future time trends to parameters, such as sectoral GDP shares, electricity consumption per dwelling, car ownership, change of energy intensity in various industry branches, etc. On the other hand, it is questionable whether one can develop a model that is general and flexible enough to be applied to a macro region and that rigorously treats the aspects mentioned above. In the scenario approach adopted for this study, the question of consistency could not be resolved in every detail. However, a cross-check of the MEDEE-2 results with the shadow prices obtained from the energy supply optimization model MESSAGE as well as an ex post interpretation of sectoral energy demand projections in terms of income and price elasticities ensure a certain degree of consistency on an aggregated level.

As mentioned above, MEDEE-2 calculates thermal energy demand in terms of useful energy, and the energy demand for nonsubstitutable uses in terms of final energy. However, the supply optimization model used in the present global energy demand assessment accepts energy demand inputs only in the form of secondary energy. The first part of the missing link between useful thermal energy and secondary energy by source, namely the conversion from useful to final energy, is done by MEDEE-2 on the basis of specified values of the expected penetrations of different energy sources (e.g., noncommercial fuels, electricity, district heat, solar systems, heat pumps), into their respective potential heat markets and the end-use efficiencies (relative to the efficiency of electricity) of various final energy forms.* The main output of MEDEE-2 is final energy demand by sector (industry, transportation, household/service) and by energy source/category of use (substitutable fossil fuels for thermal uses; centralized heat supply; soft, i.e., decentralized solar systems; electricity; motor fuel; coke; feedstocks, i.e., fossil fuels used as raw material; and noncommercial fuels). In order to obtain the associated primary energy demand, one must (1) determine the shares of coal, oil, gas, charcoal, and biogas in the substitutable fossil fuel demand for thermal uses and in the feedstock requirements**; (2) add transport/distribution losses and internal energy consumption by energy producing industries (which gives secondary energy demand), and (3) determine the supply mix of the primary energy sources and the associated conversion losses. Only step (3) was handled by the supply optimization model MESSAGE; steps (1) and (2) required a "human interface."

The choice of fossil fuels is left open in MEDEE-2 because it is mainly a matter of availability and price, and shifts may occur rather quickly. (The conversion from useful thermal to final energy demand should in fact also be treated in some optimization framework, so that relative costs of competing technologies/energy sources are formally included in the calculations.) Determination of transport/distribution losses and internal consumption by energy producers is in principle a task for the supply model, because they depend on the locations selected, the choice between import and domestic production, and the technological characteristics of energy production facilities and distribution networks. Efforts are being made in IIASA's Energy Systems Program to improve the treatment of these parts of the energy chain.

The remainder of this section gives an overview of the energy demand calculations in each sector. A formal description with the equations is given in Appendix B.

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*Final energy in the form of coal, oil, gas, and the organized supply of charcoal and biogas, used for meeting useful thermal energy demand, is treated in MEDEE-2 as a single category (called substitutable fossil fuels) and only the average efficiency for this category of fuels is specified.

**Charcoal and biogas were considered as alternatives only for the developing regions; only liquid fuels were assumed to be used as feedstocks in all regions except Region II.

### *3.1.1 Industry*

All economic activities, except for those of the service sector, are included under this label in MEDEE-2. Specifically, these are agriculture, construction, mining, three manufacturing subsectors, and energy. The energy consumption of this last sector (covering electricity gas and water supply, and other energy-related activities that can be isolated) is neglected because it is related to conversion activities as calculated at a later stage by the MESSAGE model.

Three types of end-use categories are considered: specific uses of electricity (for lighting, motive power, electrolysis, etc.); thermal uses (space and water heating, low/high temperature steam generation, furnace/direct heat); and motor fuel use (mainly for motive power in nonstationary uses such as in agriculture, construction, and mining).

Because it is mostly impossible to obtain energy balances in such detail, all present uses of electricity in industry are considered "specific" (in the sense that they are unlikely to be replaced by other energy sources) and all fossil fuels, except for motor fuel, are assumed to be consumed for thermal uses. This implies that electricity penetration into thermal uses must be interpreted as incremental penetration above the levels reached today.

For the energy demand calculations, knowledge of the activity level (value added) and energy intensities (per unit value added) in each sector is required. Energy intensities must be specified in terms of final energy for motor fuel and electricity, and in terms of "electricity equivalent" for thermal uses. The breakdown of thermal uses (space and water heating, low and high temperature steam generation, furnace/direct heat) is assumed to be constant. If the breakdown is not known for each subsector, an average split must be specified.

The energy consumption of manufacturing industries depends on the activity level and on the energy demand per unit of output in each sector. Since the sectors are highly aggregated and therefore inhomogeneous, the energy intensity may change with a modified product mix as well as with increased process integration and other operational improvements. Also the energy use pattern changes as a result of substitutions of other energy sources for fossil fuels, especially with regard to thermal uses.

For thermal uses, the penetration of electricity, district heat, cogeneration, heat pump, and soft solar technologies must be estimated. The remaining energy demand is assumed to be met by fossil fuels, and is converted to final energy demand using exogenously specified end-use efficiencies for heating systems, boilers, and furnaces (these must be given relative to electricity). Electricity can penetrate into virtually all thermal uses; the potential market of the other alternatives is restricted to steam and low-temperature uses.

The demand for coke and for petrochemical feedstocks is calculated separately in MEDEE-2, since they account for a major share of total industrial energy consumption. Coke demand is related to pig-iron production, which in turn is related to steel production. Steel production as well as petrochemical feedstock demand is directly related to the value added of basic materials industries, which include these two industry branches.

### *3.1.2 Transportation*

Three types of transportation are distinguished in MEDEE-2: passenger, freight, and international and military transportation. Passenger transportation is broken down into urban and intercity categories (Table 1).

TABLE 1 Categories of energy end use considered in MEDEE-2. Energy sources are coal (CL); motor fuel – gasoline, diesel, jet fuel (MF); electricity (EL). F is basic energy demand calculated in final energy forms; U is basic energy demand calculated in useful energy forms.

| Transportation module (F) | Industry module | | Household/service module |
|---|---|---|---|
| *Personal transportation* | *Sectors* | *Processes* | *Household* |
| urban: car (MF, EL)<br>mass transit (MF, EL) | Agriculture | Motor fuel use (F) | Space heating (U): pre-/post-1975 dwellings<br>multifamily/single family<br>central heating/other |
| | Construction | Specific* electricity uses (F) | |
| intercity: car (MF)<br>plane (MF)<br>bus (MF)<br>train (CL, MF, EL) | Mining | Thermal uses (U)<br>Steam generation<br>Furnace/direct heat<br>Space and water heating | Water heating (U)<br>Cooking (U)<br>Cooling (U)<br>Electrical appliances (F) |
| | Manufacturing<br>Basic materials<br>Machinery and equipment<br>Food textiles, and other | Coke for iron-ore reduction (F) | |
| *Freight transportation* | Energy** | Use of energy products as feedstocks (F) | *Service* |
| long distance: truck (MF)<br>train (CL, MF, EL)<br>barge (MF)<br>pipeline (MF) | | | Thermal uses (U) pre-/post-1975 buildings<br>Cooling (U)<br>Electrical appliances (F) |
| local truck (MF) | | | |
| *Miscellaneous (MF)* | | | |
| International freight and passenger (air and maritime) transport | | | |

*By definition in the model, all present uses of electricity are included here.

**The energy sector should be considered separately if statistics permit. Its energy consumption should be determined in relation to conversion from primary to secondary energy.

NOTE: The restriction of certain categories here to just one or two fuel types misses other possibilities. For instance, pipelines may also use electricity or gas.

For international and military transportation only the use of liquid fuels is considered feasible. Data for this category are often difficult to find, and the motor fuel demand of this type of transportation is therefore treated simplistically as a function of GDP.

The demand for domestic freight transportation (measured in net ton-kilometers) is calculated as a function of the GDP contribution by the agricultural, mining, manufacturing, and energy sectors. The modal split, i.e., the allocation to the various modes (rail, truck, inland waterways or coastal shipping, pipeline), must be specified exogenously, as well as the energy intensity (per ton-kilometer) of each mode. Except for rail, where electricity and coal can also be used as an energy source, only liquid fuels are assumed to be used.

Passenger transportation is treated in more detail, because in most countries it accounts for a major share of energy consumption.

Total demand for intercity passenger transportation (measured in passenger-kilometers) is calculated in MEDEE-2 from data on population and average distance travelled per person per year. Automobile travel is calculated from data on population, automobile ownership, average distance traveled per automobile per year, and an average load factor (passenger-kilometer per vehicle-kilometer). The remainder is allocated to public transportation modes (rail, bus, airplane) according to exogenously specified shares. The corresponding vehicle-kilometers are calculated from average load factors for each mode. The energy intensities (per vehicle-kilometer) also have to be specified. For freight transportation, except for railways, only liquid fuels are assumed to be used.

Total demand for urban transportation is related to the population in large cities* where mass transportation is feasible. It is calculated from data on the average distance traveled per day and per person in urban areas and on the total population living in these areas. The energy consumption related to this demand is determined from exogenously specified shares of various modes (private automobiles and mass transportation powered by motor fuel or electricity), together with average load factors and energy intensities of each mode.

All energy demand in the transport sector is calculated only in terms of final energy.

### *3.1.3 Households and Services*

Currently, in the developed countries space heating accounts for the major share of energy consumption in the household sector, and with improved insulation this energy demand could be reduced considerably. Buildings constructed after the world's acknowledgment of the energy crisis in 1973 have better insulation. To allow for this difference, pre-1975 and post-1975 buildings are treated separately in MEDEE-2. In addition, three types of dwellings are considered: single housing units with central heating, apartments with central heating, and dwellings with room heating only. This is in order to allow for the large differences in the average heat loss of these dwelling types.

The change in the housing stock of the residential sector is determined from data on average family size and population, on demolition of existing dwellings by type, and on construction of new dwellings by type. Allowance is made for the reduction of heat

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*Cities with more than 50,000 inhabitants in Regions I, III, and those with more than 100,000 inhabitants in the developing Regions IV, V, VI. For Region II all urban population has been included in this category.

loss in old dwellings through retrofitting; the heat loss of post-1975 dwellings is calculated from data on the average size and the specific heat loss (per $m^2$) for each type of dwelling.

Energy demand for water heating, cooking, air-conditioning, and the electricity consumption of secondary appliances (such as washing machine, refrigerator, freezer, dishwasher, clothes dryer, vacuum cleaner) is calculated from exogenously specified ownership fractions and/or average annual consumption rates.

The change in the building stock of the commercial/service sector is calculated from data on the average floor area per worker and labor force, and on the demolition of existing floor area. Allowance is made for improving the insulation of old buildings. Besides thermal uses (space/water heating), two other end-use categories are distinguished, namely air-conditioning and specific electricity uses, for which penetration and/or average consumption rates must be given.

The energy demand calculations for this sector are generally made in terms of "electricity equivalent." For air-conditioning, electricity is considered the only energy source; this is also true for heat pumps. In all other instances, the penetration of alternative sources, such as electricity, district heat, heat pumps, or soft solar technology, must be estimated. The remaining energy demand is assumed to be met by fossil fuels and converted to final energy demand using exogenously specified end-use efficiencies. The potential market for district heat is restricted to large cities, and the potential market for solar is restricted to post-1975 single housing units in the case of space heating; penetration of solar technology for thermal uses in the commercial/service sector is also assumed to be feasible only in low-rise buildings.

### 3.2 Input Data Requirements

There are some 180 parameters in the input data files of MEDEE-2 serving to capture such essential features of the economy, demography, technology, lifestyle, and various social and industrial activities of a country or region that have, or may have in the foreseeable future, some effect on the amount and pattern of final energy consumption. These parameters are *constants* or *variables*. *Constants* are understood to comprise initial values as well as coefficients held constant in the model calculations. *Variables* are time-dependent parameters for which scenario values have to be assigned for each model year. A complete listing of all the parameters and their definition is given in Appendix B.

## 4 TWO SCENARIOS: BASIC ELEMENTS

The future evolution of world energy demand is governed essentially by three basic elements: population growth, economic growth, and technological developments. The last two elements, which are to a certain extent interdependent, are also influenced by the relative availability of energy as a source of power, and its price.

The starting point for IIASA's energy demand projections 1975–2030 is the definition of two scenarios (Chant 1981) describing the evolution over time of population and economic growth in the seven world regions specified in Figure 1. The population projections common to both scenarios are based on Keyfitz (1977). These scenarios are labeled

High and Low in terms of two different levels of world economic growth, which cover a range of plausible economic developments in the regions in a mutually consistent manner. The figures for economic growth projections have been arrived at after several iterations through the modeling loop of Figure 2, until the energy prices and the investment requirements of the energy sector obtained for the various world regions were considered to be consistent with their envisaged economic growth rates. (See Basile 1980, Chant 1981, Energy Systems Program Group 1981, for a more detailed discussion.)

Tables 2, 3, and 4 list the projections of population and GDP in various world regions that serve as basic inputs to the energy demand assessment to be discussed. The population projections for the world as a whole as well as by groups of developed (I, II and III) and developing (IV,V,VI, and VII) regions are plotted in Figure 5. Note that the period of consideration is one in which the world population is expected to undergo a major transition, with a predominant increase occurring in the areas of the currently developing economies.

TABLE 2 Population projections by region ($10^6$).

| | | Projections | |
|---|---|---|---|
| Region | 1975 | 2000 | 2030 |
| I (NA) | 237 | 284 | 315 |
| II (SU/EE) | 363 | 436 | 480 |
| III (WE/JANZ) | 560 | 680 | 767 |
| IV (LA) | 319 | 575 | 797 |
| V (Af/SEA) | 1,422 | 2,528 | 3,550 |
| VI (ME/NAf) | 133 | 247 | 353 |
| VII (C/CPA) | 912 | 1,330 | 1,714 |
| World | 3,946 | 6,080 | 7,976 |

NOTE: 1975 data are mid-year estimates from United Nations Monthly Bulletin of Statistics, January 1978.
The same population projection is chosen for both High and Low scenarios.
SOURCE: Keyfitz (1977).

Depletion of energy resources, increasing production costs and rising prices of energy commodities traded internationally over the next 50 years are only qualitatively accounted for in this assessment. (For a detailed discussion with respect to the two IIASA scenarios, see Energy Systems Program Group 1981.) These issues influenced the projections of some scenario parameters of the MEDEE-2 model, and occasionally required a modification of the values used in a previous iteration of the modeling loop of Figure 2. For our purpose, it should suffice to point out two important results of the supply analysis of the two scenarios. The biggest difficulty in energy supply, which is to be felt worldwide, will be to meet the demand for liquid fuel. Further, by 2030, the average final energy production costs will increase to about 2.9 to 4.2 times the 1972 values (with the corresponding prices probably increasing to 2.4 to 3.0 times the 1972 prices) in the various world regions (Chant 1981).

TABLE 3 GDP projections by region ($10^9$ \$1975).

| | | Projections | | | |
|---|---|---|---|---|---|
| | | High scenario | | Low scenario | |
| Region | 1975 | 2000 | 2030 | 2000 | 2030 |
| I (NA) | 1,670 | 4,126 | 7,926 | 3 049 | 4,170 |
| II (SU/EE) | 930 | 2 729 | 7,658 | 2,420 | 4,713 |
| III (WE/JANZ) | 2,385 | 5,999 | 11 693 | 4,452 | 6,656 |
| IV (LA) | 340 | 1,272 | 3,569 | 918 | 2,229 |
| V (Af/SEA) | 340 | 1.207 | 3,488 | 924 | 1,995 |
| VI (ME/NAf) | 190 | 900 | 2,918 | 643 | 1,310 |
| VII (C/CPA) | 320 | 939 | 2,450 | 690 | 1,345 |
| World | 6,175 | 17,172 | 39,702 | 13,096 | 22,418 |

NOTE: GDP in constant 1975 US dollars. Base year data are estimates from UN (1977c), World Bank (1977) and OECD (1979a).

TABLE 4 GDP per capita projections by region ($10^3$ \$1975).

| | | Projections | | | |
|---|---|---|---|---|---|
| | | High scenario | | Low scenario | |
| Region | 1975 | 2000 | 2030 | 2000 | 2030 |
| I (NA) | 7.05 | 14.53 | 25.16 | 10.74 | 13.24 |
| II (SU/EE) | 2.56 | 6.26 | 15.95 | 5.55 | 9.82 |
| III (WE/JANZ) | 4.26 | 8.82 | 15.25 | 6.55 | 8.68 |
| IV (LA) | 1.07 | 2.21 | 4.48 | 1.60 | 2.80 |
| V (Af/SEA) | 0.24 | 0.48 | 0.98 | 0.37 | 0.56 |
| VI (ME/NAf) | 1.43 | 3.64 | 8.27 | 2.60 | 3.71 |
| VII (C/CPA) | 0.35 | 0.71 | 1.43 | 0.52 | 0.78 |
| World | 1.56 | 2.82 | 4.98 | 2.15 | 2.81 |

NOTE: Based on Tables 2 and 3.

## 5 APPLICATION OF MEDEE-2 TO IIASA REGIONS I TO VI

### 5.1 Base Year Data/Inputs

As is evident from Section 3, assessment of future energy demand following the MEDEE-2 approach requires base year data of a large number of parameters as well as projected values of these parameters that are consistent with the basic scenario elements (Section 4) for each world region. For some of these parameters, statistical information detailed by countries or by groups of countries is available from United Nations (UN), International Bank for Reconstruction and Development (IBRD), Food and Agriculture Organization (FAO), International Road Federation (IRF), Organization for Economic Cooperation and Development (OECD), Economic Commission for Europe (ECE) etc., while for others the information is either limited to only a few countries (mostly contained in national statistical bulletins) or is not documented at all.

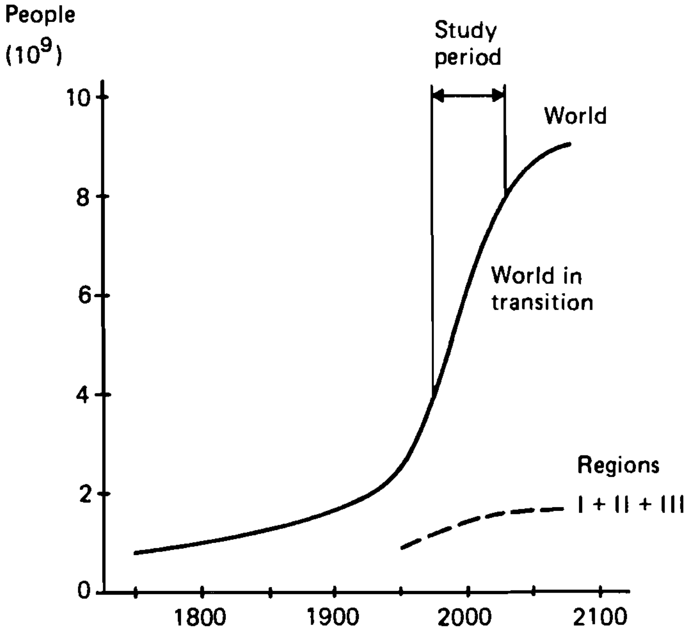

FIGURE 5 World population – historical and projected.

Overall, the data base situation is considerably more satisfactory for the developed Regions I, II and III than it is for the developing Regions IV, V, and VI. In some cases we had to rely on extrapolation of regional averages from information on just a few countries (sometimes only on one) in a given region, or on estimates we made on the basis of scattered material in the literature and from discussion with knowledgable persons from countries in these regions.

In spite of these difficulties, we feel that the base year data for all the regions represent fairly well the regional average situations prevailing in 1975. One should keep in mind, however, that the purpose of this project was to conceptualize the present energy demand pattern in each world region and to arrive at projections of the demands for specific and substitutable energy forms. This was achieved while considering the likely evolution of various socioeconomic activities in line with the basic assumptions of the two IIASA scenarios. This report documents the complete set of input data for the base year (1975) for each world region as it was used in the IIASA analysis (Energy Systems Program Group 1981). It is hoped that some of these data will be refined in due course, as improved and/or more complete information becomes available. We now briefly describe how the base year data related to various groups of parameters were obtained.

The starting point for this exercise was to determine primary energy consumption in the form of both commercial and noncommercial fuels. These data are listed in Table 5. The data on commercial energy consumption in Regions II, IV, V, and VI are based on World Energy Supplies (UN 1977a, 1978a), and those of Regions I and III are derived basically from OECD Energy Statistics (OECD 1977). For noncommercial energy, the data on fuelwood are based on World Energy Supplies (UN 1977a, 1978a), and those for

TABLE 5 Primary energy consumption, electricity generation and noncommercial energy use in the base year (1975) by region.

| | Region | | | | | |
|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI |
| *Primary energy consumption* (GWyr) | | | | | | |
| Solid | 484 | 770 | 541 | 16 | 119 | 3 |
| Liquid | 1,167 | 635 | 1,252 | 228 | 159 | 77 |
| Natural gas | 763 | 374 | 238 | 48 | 20 | 43 |
| Hydro (primary equiv.) | 174 | 50 | 180 | 45 | 29 | 5 |
| Nuclear (primary equiv.) | 66 | 6 | 45 | 1 | 1 | 0 |
| Total | 2,654 | 1,835 | 2,256 | 338 | 328 | 128 |
| *Electricity generation* (GWyr) | | | | | | |
| Hydro | 58 | 17 | 59 | 15.1 | 9.9 | 1.5 |
| Conventional thermal (from fossil fuels) | 181 | 139 | 167 | 12.6 | 16.0 | 3.9 |
| Nuclear | 21 | 2 | 15 | 0.3 | 0.4 | 0 |
| Total | 260 | 158 | 241 | 28 | 26 | 5 |
| *Noncommercial fuels* (GWyr) | | | | | | |
| Wood | – | 44 | – | 84 | 229 | 2 |
| Agricultural and animal wastes | – | – | – | 25 | 115 | 8 |
| Total | – | 44 | – | 109 | 344 | 10 |

agricultural and animal wastes on the estimates by Parikh (1978) together with information on agricultural production given in FAO (1977). The noncommercial energy use in Regions I and III, as compared to the use of commercial fuels, is insignificantly small and has been ignored.

The MEDEE-2 calculations lead to only final energy and not to primary energy. Thus, in adjusting the various base year parameters to match the actual energy consumption, one needs to know the final consumption in terms of electricity as well as in non-electric energy forms. Such information is readily available for Region I, for most of Region III, and for part of Region II (Eastern Europe) in OECD (1977) and ECE (1977). The missing information on these and other regions is obtained by assuming appropriate conversion (primary to secondary) and distribution (secondary to final) losses typical of different fuels, as well as an appropriate fuel mix for thermal electricity (and, in the case of Region II, district heat) generation in the various regions. The final energy estimates for the base year are listed in Table 6.

Information on the sectoral distribution of final energy in Region I, in the Eastern Europe part of Region II, and in the OECD section of Region III is also available in OECD (1977) and ECE (1977). Similar information on the developing regions is derived partly from sectoral primary energy consumption data for certain countries -- Brazil, Mexico, India, Pakistan, Egypt, Saudi Arabia (Vieira 1978, WAES 1976, Parikh 1976, Henderson 1975, Pakistan 1977, Elshafei 1978, Saudi Arabia 1977) – and partly by adjusting the less certain MEDEE-2 parameters to match the total final energy demand.* These estimates

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*A recent publication by OECD (1979b) giving information on energy consumption data for sectoral activities in sixteen developing countries was not available at the time of the assessment.

TABLE 6 Estimate of final energy use by energy form and by region in the base year (1975).

| | Region | | | | | |
|---|---|---|---|---|---|---|
| Energy form (GWyr) | I | II | III | IV | V | VI |
| Coal[a] | 108 | 353 | 232 | 12 | 81 | 2 |
| Oil[b] | 951 | 428 | 979 | 189 | 138 | 70 |
| Gas[c] | 584 | 148 | 177 | 29 | 12 | 29 |
| Electricity | 228 | 130 | 201 | 24 | 22 | 5 |
| District heat | – | 218 | – | – | – | – |
| Total | 1,871 | 1,277 | 1,589 | 254 | 253 | 106 |

[a] Includes coke consumption of the iron and steel industry.
[b] Includes feedstocks derived from crude oil.
[c] Includes manufactured gas.

TABLE 7 Estimate of sectoral distribution of final energy use in the base year (1975).

| | Region | | | | | |
|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI |
| *Total final energy* (GWyr) | 1,871 | 1,277 | 1,589 | 254 | 253 | 106 |
| % electricity | 12.2 | 10.2 | 12.7 | 9.6 | 8.1 | 4.4 |
| % district heat | – | 17.7 | – | – | – | – |
| *Industry* (GWyr) | 757 | 759 | 805 | 119 | 149 | 49 |
| % electricity | 12.5 | 13.3 | 14.0 | 14.5 | 11.9 | 7.5 |
| % district heat | – | 22.4 | – | – | – | – |
| *Transport* (GWyr) | 541 | 224 | 313 | 105 | 76 | 42 |
| % electricity | 0.1 | 4.0 | 1.9 | 0.2 | 0.5 | 0.1 |
| *Household/service* (GWyr) | 573 | 293 | 471 | 31 | 28 | 15 |
| % electricity | 23.3 | 6.9 | 17.6 | 22.7 | 13.6 | 6.6 |
| % district heat | – | 16.4 | – | – | – | – |
| *Noncommercial energy* households only) (GWyr) | – | 44 | – | 109 | 344 | 10 |

are summarized in Table 7.

The base year input parameters (see Appendix B for definitions) for MEDEE-2 are discussed; the groups covered are (1) demography; (2) macroeconomics; and (3) energy consumption by the industry, transportation, and household/service sectors. They are listed in Table 8, and the corresponding sources of information are given below. In order to obtain the appropriate regional values, additional calculations and/or extrapolations were necessary in most cases.

### *5.1.1 Demography*

*Parameters in Group 1 of Table 8.* The sources of information for the various parameters were as follows:

| *Variable* | *Reference* |
|---|---|
| *PO* (population) | UN (1977b, 1978b) |
| *PLF* (potential labor force) | UN (1976a) |
| *PARTLF* (participation rate of the potential labor force) | US (1976a) and Canada (1975) for Region I<br>CMEA (1976) for Region II<br>ILO (1976) for Region III<br>FAO (1977) for Regions IV, V, VI |
| *POLC* (population outside large cities) | UN (1976b) for Regions IV, V, VI; Paxton (1976) for Regions I and III. CMEA (1976) for Region II |
| *PRUR* (rural population) | UN (1976b) |
| *CAPH* (persons per dwelling) | ECE (1978a) for Regions I, II, III<br>UN (1974) for Regions IV, V, VI |

TABLE 8 Base year data/inputs.

| | Region | | | | | |
|---|---|---|---|---|---|---|
| Variable | I | II | III | IV | V | VI |
| Group 1: Demography | | | | | | |
| *PO* | 237 | 363 | 560 | 319 | 1,422 | 133 |
| *PLF* | 0.64 | 0.64 | 0.63 | 0.542 | 0.538 | 0.523 |
| *PARTLF* | 0.69 | 0.61 | 0.72 | 0.59 | 0.708 | 0.512 |
| *POLC* | 0.64 | 0.42 | 0.51 | 0.63 | 0.87 | 0.71 |
| *PRUR** | 0.24 | 0.41 | 0.29 | 0.40 | 0.78 | 0.55 |
| *CAPH* | 2.98 | 3.7 | 3 | 5.1 | 5.24 | 5.25 |
| Group 2: Macroeconomics | | | | | | |
| *Y* | 1,670 | 930 | 2,385 | 340 | 340 | 190 |
| *PYAG* | 0.028 | 0.107 | 0.058 | 0.122 | 0.361 | 0.07 |
| *PYB* | 0.041 | 0.079 | 0.075 | 0.057 | 0.058 | 0.065 |
| *PYMIN*** | 0 | 0 | 0 | 0.025 | 0.015 | 0.51 |
| *PYMAN* | 0.245 | 0.382 | 0.336 | 0.248 | 0.166 | 0.078 |
| *PYEN* | 0.038 | 0.042 | 0.046 | 0.025 | 0.016 | 0.007 |
| *PYSER* | 0.648 | 0.39 | 0.485 | 0.523 | 0.384 | 0.27 |
| *PVAIG* | 0.248 | 0.233 | 0.33 | 0.308 | 0.264 | 0.2 |
| *PYAM* | 0.432 | 0.476 | 0.42 | 0.264 | 0.176 | 0.1 |
| *PVAC* | 0.32 | 0.291 | 0.25 | 0.429 | 0.56 | 0.7 |
| *I** | 0.18 | 0.3 | 0.25 | 0.23 | 0.2 | 0.215 |
| *P** | 0.65 | 0.45 | 0.58 | 0.7 | 0.71 | 0.325 |
| *PCDG** | 0.19 | 0.1 | 0.1 | 0.1 | 0.07 | 0.1 |
| *PCNDG** | 0.42 | 0.6 | 0.56 | 0.6 | 0.73 | 0.6 |
| *PCSER** | 0.39 | 0.3 | 0.34 | 0.3 | 0.2 | 0.3 |

*The values for these variables do not directly affect the calculations of the version of the MEDEE-2 model used for the present assessment, but they are used for projecting the evolution of other variables, outside the model calculations.

**For Regions I, II, and III, mining of coal, oil, and gas is included in the energy sector and that of other materials is included under manufacturing of basic materials. (See definition of sectors in Appendix C.)

NOTE: See definition of variables in Appendix B, Part 2.

### *5.1.2 Macroeconomics*

*Parameters in Group 2 of Table 8.* The sources of data were the following:

| *Variable* | *Reference* |
|---|---|
| $Y$ (total GDP) | UN (1977c), World Bank (1977), OECD (1979a) |
| All other data | UN (1977b) for Regions I, II, III<br>UN (1977c) and data supplied by Arab Fund (1979) for Regions IV, V, VI |

### *5.1.3 Energy Consumption in Sectors*

#### *I Industry (Agriculture, Construction, Mining, and Manufacturing)*

*(i) Parameters in Groups 3.1a and 3.1b in Table 8.* The data for Region I are based on estimates for the US made by Lapillonne (1978b) using the information given in WAES (1976) and Doblin (1978). The values estimated for Region III are based on data for Austria (Foell et al. 1979), France (Lapillonne 1978c) and the US. The estimates for Region II were made partly on the basis of data contained in Vigdorchik (1976), USSR

TABLE 8 Base year data/inputs *(continued)*.

| | Region | | | | | |
|---|---|---|---|---|---|---|
| Variable | I | II | III | IV | V | VI |
| **Group 3: Energy Consumption** | | | | | | |
| *Group 3.1: Industry (Agriculture, Construction, Mining, Manufacturing)* | | | | | | |
| Group 3.1a: Energy Intensity of Agriculture , Construction, Mining | | | | | | |
| *EI.AGR.MF* | 5.07 | 1.36 | 1.49 | 0.132 | 0.165 | 0.252 |
| *EI.AGR.EL* | 0.56 | 0.88 | a | 0.062 | 0.1 | 0.065 |
| *EI.AGR.TH* | a | a | a | a | a | a |
| *EI.CON.MF* | 2.53 | 2.56 | 1.97 | 1.44 | 0.05 | 0.25 |
| *EI.CON.EL* | a | 0.95 | a | 0.065 | a | a |
| *EI.CON.TH* | a | a | a | a | a | a |
| *EI.MIN.MF* | b | b | b | 5.1 | 1.47 | a |
| *EI.MIN.EL* | b | b | b | 1.82 | a | a |
| *EI.MIN.TH* | b | b | b | a | a | 1.366 |
| Group 3.1b: Energy Intensity of Manufacturing Industries | | | | | | |
| *EI.BM.MF* | 0.14 | a | a | a | a | a |
| *EL.BM.EL* | 4.62 | 5 | 1.27 | 2.35 | 5.5 | 4.4 |
| *EI.BM.US* | 18.05 | 17.286 | 5.81 | 7.38 | 12.5 | 11.74 |
| *EI.ME.MF* | a | a | a | a | a | a |
| *EI.ME.EL* | 0.9 | 1.5 | 1.87 | 0.68 | 1.85 | 0.66 |
| *EI.ME.US* | 1.14 | 4.4 | 0.81 | 0.576 | 1.025 | 1.89 |
| *EI.ND.MF* | a | a | a | a | a | a |
| *EI.ND.EL* | 1.32 | 0.58 | 0.23 | 1.54 | 1.38 | 1.69 |
| *EI.ND.US* | 2.48 | 5 | 1.06 | 2.868 | 6.85 | 3.19 |

TABLE 8 Base year data/inputs *(continued)*.

| | Region | | | | | |
|---|---|---|---|---|---|---|
| Variable | I | II | III | IV | V | VI |
| Group 3.1c: Change of Energy Intensity of Agriculture, Construction, Mining | | | | | | |
| *CH.AGR.MF* | 1 | 1 | 1 | 1 | 1 | 1 |
| *CH.AGR.EL* | 1 | 1 | 1 | 1 | 1 | 1 |
| *CG.AGR.TH* | 1 | 1 | 1 | 1 | 1 | 1 |
| *CH.CON.MF* | 1 | 1 | 1 | 1 | 1 | 1 |
| *CH.CON.EL* | 1 | 1 | 1 | 1 | 1 | 1 |
| *CH.CON.TH* | 1 | 1 | 1 | 1 | 1 | 1 |
| *CH.MIN.MF* | 1 | 1 | 1 | 1 | 1 | 1 |
| *CH.MIN.EL* | 1 | 1 | 1 | 1 | 1 | 1 |
| *CH.MIN.TH* | 1 | 1 | 1 | 1 | 1 | 1 |
| Group 3.1d: Change of Energy Intensity of Manufacturing Industries | | | | | | |
| *CH.MAN.MF* | 1 | 1 | 1 | 1 | 1 | 1 |
| *CH.MAN.EL* | 1 | 1 | 1 | 1 | 1 | 1 |
| *CH.MAN.US* | 1 | 1 | 1 | 1 | 1 | 1 |

a: Separate data were not available; the corresponding requirements are accounted for elsewhere.
b: The mining sector is not considered separately for Regions I, II, and III (see definition of PYMIN, PYEN, PYMAN and PVAIG in Appendix C).

(1976), and partly by comparison with Regions I and III. For Regions IV and V, the values were in general derived by combining the sectoral energy consumption data of a few countries, i.e., of Brazil (Vieira 1978) for Region IV, and of India (Parikh 1976) and Pakistan (1977) for Region V for recent years, and the corresponding value-added contributions to respective national GDPs (UN 1977c). The data for Region VI were estimated by adjusting the values obtained for Egypt from the energy consumption data given by Elshafei (1978) in the light of those for Regions IV and V.

The energy intensity values for agriculture (*EI.AGR.MF* for motor fuel and *EI.AGR.EL* for electricity) in Regions IV, V, and VI were also adjusted taking into account the extent of farm mechanization and irrigation in these regions (FAO 1977). The energy intensity of mining in Region VI was estimated from the data given by Chapman and Hemming (1976) and Saudi Arabia (1977).

*(ii) Parameters in Group 3.1c and 3.1d in Table 8.* These parameters are used to project future changes in energy intensity of various industrial activities relative to the base year values. Each of the parameters is by definition equal to unity in the base year.

*(iii) Parameters in Group 3.1e in Table 8.* At the time the present set of model runs was carried out, detailed information on these parameters was available to us only for the US (APS 1975; Lovins 1977), but we had some partial information on the USSR (Vigdorchik 1976). This is the basic information used for the estimates of these parameters in all regions, although some adjustments were made to account for the different climatic conditions in the regions. Detailed information recently published for the UK (Leach et al. 1979) indicates slightly higher values for *STSHI* (share of steam and low temperature heat) and *STI* (share of steam only), but the differences are not significant for our results.

TABLE 8 Base year data/inputs *(continued)*.

| Variable | Region<br>I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| Group 3.1e: Breakdown of Useful Thermal Energy in Manufacturing Industries | | | | | | |
| *STSHI* | 0.5 | 0.69 | 0.5 | 0.42 | 0.4 | 0.4 |
| *STI* | 0.4 | 0.6 | 0.4 | 0.4 | 0.4 | 0.4 |
| *LTH* | 0.2 | 0.3 | 0.2 | 0.15 | 0.15 | 0.15 |
| Group 3.1f: Penetration of Alternative Energy Sources and Efficiences† | | | | | | |
| *ELPIND* (4)* | 0 | 0 | 0 | 0 | 0 | 0 |
| *(HPI)* | (0) | (0) | (0) | (0) | (0) | (0) |
| *EFFHPI* | 2 | 2 | 2 | 2 | 2 | 2 |
| *IDH* | 0 | 0.69 | 0 | 0 | 0 | 0 |
| *SPLT* | 0 | 0 | 0 | 0 | 0 | 0 |
| *SPHT* | 0 | 0 | 0 | 0 | 0 | 0 |
| *FIDS* | 0.7 | 0.3 | 0.7 | 0.8 | 0.8 | 0.8 |
| *ICOGEN* | 0 | 0 | 0.3 | 0 | 0 | 0 |
| *EFFCOG* | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 |
| *HELRAT* | 5 | 5 | 5 | 5 | 5 | 5 |
| *EFFIND* (4)** | 0.85 | 0.605 | 0.65 | 0.8 | 0.6 | 0.55 |

*Zero by definition, i.e., only penetration above levels reached today is considered.

**Efficiency of fossil fuel use relative to electricity.

†Values in parentheses are to be interpreted as fractions of the preceding category.

*(iv) Parameters in Group 3.1f in Table 8.* Among these parameters, relating to the penetration of alternative energy sources into the thermal energy market, *ELPIND* (electricity) is by definition zero for the base year. *HPI* (heat pump), *SPLT* (solar/low temperature uses), and *SPHT* (solar/high temperature uses) are zero in 1975 in all regions, and consequently *EFFHPI* (efficiency of heat pumps) and *FIDS* (load factor of solar installations) are ineffective. *IDH* (district heat) has a large value for Region II (Vigdorchik 1976), but was considered negligible for other regions. *ICOGEN* (cogeneration of steam and electricity within industry) applies, as a significant base year parameter, only to Region III where cogeneration is used appreciably in certain countries (in particular UK, FRG, Sweden). *EFFCOG* (system efficiency of cogeneration) and *HELRAT* (heat to electricity ratio) are significant only when *ICOGEN* has a nonzero value. The listed values for these parameters are based on Leach et al. (1979).

*EFFIND* represents the average value of the fossil fuel efficiency for all fossil fuels (oil, gas, coal) and all thermal processes (low temperature heat, steam, furnace heat). It is difficult to specify a regional value of this parameter as the combustion efficiencies of gas, oil, and coal differ greatly among each other and since the shares of these sources vary between countries. *EFFIND*, therefore, is largely of indicative value. The fossil fuel efficiency values in the literature (e.g., Eurostat 1978; Beschinsky and Kogan 1976), expressed relative to the efficiency of electricity, vary between 30 and 80 percent for the developed regions. They are in the lower range for high-temperature processes and in the upper range for low-temperature processes. The values are generally expected to be lower for the developing regions, where the equipment is not the most modern and is often not well maintained. The efficiency would be the lowest in Region V, where coal is still used

TABLE 8 Base year data/inputs *(continued)*.

| | Region | | | | | |
|---|---|---|---|---|---|---|
| Variable | I | II | III | IV | V | VI |
| Group 3.1g: Constants for Projection of Feedstock Use and Steel Production | | | | | | |
| *CFEED* (1) | 0 | −44.3 | 0 | 0 | 0 | 5.6 |
| *CFEED* (2) | 0.77 | 1 | 0.36 | 0.488 | 0.553 | 0.4 |
| *CPST* (1) | 0 | 71.4 | 0 | 0 | 0 | 0 |
| *CPST* (2) | 0.49 | 1.33 | 0.83 | 0.732 | 0.606 | 0.304 |
| Group 3.1h: Coke Use in Iron and Steel Industry | | | | | | |
| *BOF* | 0.8 | 0.8 | 0.8 | 1 | 1 | 1 |
| *IRONST* | 0.97 | 0.9 | 0.97 | 0.6 | 0.95 | 1.2 |
| *EICOK* | 600 | 700 | 500 | 600 | 900 | 1,000 |

in large proportions. The values listed for *EFFIND* in Table 8 were estimated and, if necessary, adjusted in the light of the above consideration.

*(v) Parameters in Groups 3.1g and 3.1h in Table 8.* As indicated in Appendix B, the parameters of Group 3.1g are the fixed coefficients C(1) and C(2) of the expressions C(1) + C(2) X X relating the use of petrochemical feestocks (*CFEED*) and the production of steel (*CPST*) to the value-added contribution of the basic materials industries in each region. In principle, these coefficients can be determined on the basis of the actual production data over the last few years, if in the scenarios the past trends are assumed to continue. Alternatively, one could define the coefficients independently of the past data and only adjust them to the base year production and future target values.

In the present set of MEDEE-2 runs, *CFEED* (1) is assumed to be zero in all the regions except for Regions II and VI, and *CFEED* (2) was determined solely on the basis of the 1975 values. For Regions II and VI, the coefficients were fixed in a similar manner; they were assumed to constitute an increasing proportion of the petrochemical component in the value added of basic material industries of Region II and a declining proportion in Region VI. Coefficients *CPST* (1) and *CPST* (2) were determined likewise for all regions, except for Region II, by assuming *CPST* (1) to be zero. For Region II, the two coefficients were adjusted to the base year data under the assumption that the proportion of the steelmaking component of the basic material industries decreases with time. The base year consumptions of (liquid fuel based) petrochemical feedstocks and of steel in the various regions were estimated basically from the data given by the following sources:

| | |
|---|---|
| Feedstocks consumption (production) | OECD (1977) for Regions I, III<br>[*] UN (1977a, 1978a) for other regions |
| Steel production | UN (1977b) for Regions I, II, III<br>UN (1975, 1977d) for Regions IV, V, VI |

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[*] Feedstock consumption data were available only for Regions I and III; for other regions, production data were used, assuming that trade would be negligible.

The parameter *IRONST* (ratio of pig-iron to steel production) was estimated for all the regions from the data on pig-iron and steel production (UN 1975, 1977b, 1977d). The *EICOK* (coke rate of blast furnaces) and *BOF* (share of steel produced in nonelectric furnaces) estimates for Regions I and III are based on the data for the US and Japan (Doernberg 1977), and France (Lapillonne 1978c). For Region II, such estimates were obtained by comparison with the values for Regions I and III and taking into account the coke production data given in (UN 1977b). For Regions IV, V, and VI, *BOF* was assumed to be unity in 1975, whereas the estimates for *EICOK* were based essentially on the data on pig-iron production and coke consumption of a few countries (UN 1975, 1977d, Vieira 1978, Parikh 1976, Elshafei 1978).

### *II Transportation*

*(i) Parameters in Group 3.2a in Table 8.* The coefficients *CTKFRT* (1) and *CTKFRT* (2) (demand for freight ton-kilometers) for Region I have been taken to be the same as derived by Lapillonne (1978b) for the US, on the basis of the historical data for 1950–1975 (US 1976a, b). For Region II, these coefficients were estimated by assuming a slower growth of freight transportation activity in relation to the growth of value added from the nonservice sectors and by adjusting them to match the base year data on freight transportation (CMEA 1976) and GDP formation. For Regions III, IV, V, and VI, *CTKFRT* (1) was assumed to be zero; the values of *CTKFRT* (2) were worked out on the basis of estimated total freight transportation activity in 1975 in each region and the corresponding GDP formation data. Freight transportation on trains is given in detail in UN (1977b). Information on freight transportation by truck, barge, and pipeline for several countries in each region was gathered from various national statistics and other sources, in particular IRF (1976), WAES (1976), Europa (1974), and WFB (1974). This information served to estimate the total freight transportation activity in groups of countries in each region; the latter values were then extrapolated to the regional level by GDP weighting. Often, data on freight transportation were not given in ton-km but had to be estimated from information on total tons transported, number of vehicles, vehicle-km, average distance travelled per vehicle, lengths and diameters of pipelines, etc.

TABLE 8 Base year data/inputs *(continued).*

| | Region | | | | | |
|---|---|---|---|---|---|---|
| Variable | I | II | III | IV | V | VI |
| *Group 3.2: Transportation* | | | | | | |
| Group 3.2a: Constants for Projecting Freight and Miscellaneous Transportation | | | | | | |
| *CTKFRT* (1) | −118.45 | 1,120 | 0 | 0 | 0 | 0 |
| *CTKFRT* (2) | 6.125 | 7.12 | 1.45 | 6.19 | 2.83 | 4.353 |
| *CMISMF* (1) | 0 | 560 | 0 | 0 | 0 | 0 |
| *CMISMF* (2) | 0.225 | 0.3 | 0.07 | 0.16 | 0.16 | 0.2 |

Coefficients *CMISMF* (1) and *CMISMF* (2) refer to motor fuel consumption for miscellaneous transportation activities including military and international transportation.

In MEDEE-2, these activities are assumed to vary linearly with GDP. Data necessary for estimating these coefficients are generally not available except for the US in Region I. The coefficients for Region I used here are based on the estimates made by Lapillonne (1978b) and are in agreement with the information given in WAES (1976). For other market economy regions, *CMISMF* (1) is assumed to be zero, as for Region I, and the values of *CMISMF* (2) have been chosen in the light of information on international travel/freight transportation and the expenditures (as fraction of GDP) on military activities in different regions relative to that in the US (US 1976a). For Region II, it is assumed that the present per capita level of motor fuel consumption for these activities is comparable to that in Region I. It is further assumed that the absolute demand for such activities will grow more slowly than GDP, in view of the relatively faster growth of GDP expected for this region among the developed regions. We realize that our input values of *CMISMF* (1) and *CMISMF* (2) for various regions are particularly uncertain, but this is due to the present limitations of data availability.

*(ii) Parameters in Group 3.2b in Table 8.* These parameters refer to fractional shares of different modes in total freight transportation. The parameters in parentheses represent certain subcategories of the preceding mode. The values for these parameters were obtained simultaneously with those of total freight ton-km discussed earlier in connection with the *CTKFRT* coefficient, and the same sources of data apply. Subcategory *TRUL* (local truck transport) was not considered separately except for Region I.

*(iii) Parameters in Group 3.2c in Table 8.* The values of the first four of these parameters for Region I are the same as those derived by Lapillonne (1978b) on the basis of data given in US (1976a), ATA (1975), and FEA (1974a). Estimates of these parameters for Region III were obtained on the basis of data given in WAES (1976), Goen (1975),

TABLE 8 Base year data/inputs *(continued)*.

| | Region | | | | | |
|---|---|---|---|---|---|---|
| Variable | I | II | III | IV | V | VI |
| Group 3.2b: Distribution of Freight Transportation by Mode* | | | | | | |
| *TRU* | 0.234 | 0.025 | 0.55 | 0.615 | 0.45 | 0.426 |
| *(TRUL)* | (0.15) | (0) | (0) | (0) | (0) | (0) |
| *FTRA* | 0.39 | 0.775 | 0.3 | 0.175 | 0.35 | 0.024 |
| *(TRAEF)* | (0) | (0.35) | (0.3) | (0.01) | (0.15) | (0.05) |
| *(TRASTF)* | (0) | (0.055) | (0) | (0) | (0.55) | (0) |
| *BA* | 0.164 | 0.05 | 0.1 | 0.15 | 0.08 | 0.03 |
| *PIP* | 0.212 | 0.15 | 0.05 | 0.06 | 0.12 | 0.52 |
| Group 3.2c: Energy Intensity of Freight Transportation Modes | | | | | | |
| *DTRU* | 400 | 800 | 800 | 800 | 800 | 800 |
| *DTRUL* | 1,100 | 0 | 0 | 0 | 0 | 0 |
| *DTRAF* | 110 | 100 | 200 | 200 | 200 | 200 |
| *DBA* | 80 | 100 | 200 | 200 | 200 | 200 |
| *DPIP* | 0 | 0 | 0 | 0 | 0 | 70 |

*Values in parentheses are to be interpreted as fractions of the preceding category.

Japan (1978), CEC (1978), and Lapillonne (1978c). The values chosen for Region II are similar to those for Region I as the average distance per freight movement is similar. The values used for Regions IV, V, and VI are identical with those for Region III.

Parameter *DTRUL* (energy intensity of local truck transport) applies only to Region I, where local truck movements are considered separately from long-distance hauls. The value of parameter *DPIP* is based on information given in ECE (1976). Energy consumption due to pipeline transportation is significant only in Region VI, and was neglected for other regions.

Not included in Group 3.2c are the efficiencies of electric and steam-operated trains. These efficiencies were internally fixed within the model respectively as one-third and three times the efficiency of diesel trains.

*(iv) Parameters in Groups 3.2d to 3.2g in Table 8.* The parameter values for Region I in these four groups were obtained on the basis of data in US (1976a), Hirst (1974a, b), IEA (1976), ATA (1975) FEA (1974a), WAES (1976), and Hittman (1974), and are, in general, the same as used for the US study (Lapillonne 1978b). The information for Region III was derived on the basis of Goen (1975), Japan (1978), WAES (1976), UN (1977b), IRF (1976), and by comparison with the data for Region I. The input data for Region II are based partly on UN (1977b), CMEA (1976), USSR (1976), Styrikovich (1979), and partly on comparison with Regions I and III.

For Regions IV, V, and VI the main sources of information in addition to a few national statistical publications, were UN (1977b), IRF (1976), Europa (1974), WFB (1974), and Arab Fund (1979). Some of the information available was limited to a few countries in each of the developing regions, and was extrapolated to obtain representative regional values also on the basis of other parameters and under consideration of similarities between countries or groups of countries.

For most regions, except for Region I and partly Region III, load factors and urban travel were estimated essentially on a judgmental basis in consultation with some experts from various regions. The load factors for the developing regions were chosen to correspond to trains and vehicles of similar average sizes as are used in Region III. This was necessary in order to make use of the vehicle efficiency data established for Region III as the corresponding information for Regions IV, V, and VI was not readily available.

### *III Households and Services*

*(i) Parameters in Group 3.3a to 3.3e in Table 8.* Detailed information on the distribution of energy consumption in the household and service sectors is generally scarce, except for the US and a few countries in Region III. Still, a large number of parameters are needed to conceptualize the patterns of energy consumption in these sectors and to project the future energy demand by assuming a plausible evolution of various activities in relation to the projected population and economic growth. The values for the parameters in Table 8, Group 3* are based on available data wherever possible, on extrapolations from the data of certain countries, and on more general studies related to energy consumption.

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*Except for subgroup 3.3c, which is only relevant for the projections.

TABLE 8 Base year data/inputs *(continued)*.

| | Region | | | | | |
|---|---|---|---|---|---|---|
| Variable | I | II | III | IV | V | VI |
| Group 3.2d: Total Distance Traveled per Person (Intercity/Urban) | | | | | | |
| *DI* | 10,000 | 2,650 | 7,500 | 1,850 | 500 | 1,050 |
| *DU* | 56 | 10 | 9.7 | 16.5 | 11 | 11 |
| Group 3.2e: Car Travel* | | | | | | |
| *CO* | 2 | 40 | 5.21 | 25.64 | 268 | 59.5 |
| *DIC* | 7,000 | 5,000 | 5,000 | 6,300 | 6,700 | 6,000 |
| *LFIC* | 2.6 | 3 | 2.3 | 3.5 | 3.5 | 3 |
| *UC* | 0.966 | 0.4 | 0.7 | 0.3 | 0.33 | 0.3 |
| *(UCE)* | (0) | (0) | (0) | (0) | (0) | (0) |
| *LFUC* | 1.6 | 2.5 | 1.5 | 2.5 | 2.5 | 2 |
| Group 3.2f: Public Transportation* | | | | | | |
| *PBU* | 0.153 | 0.15 | 0.35 | 0.845 | 0.67 | 0.844 |
| *PTRA* | 0.051 | 0.62 | 0.6 | 0.107 | 0.314 | 0.132 |
| *(TRAEP)* | (0.01) | (0.5) | (0.3) | (0.01) | (0.15) | (0.05) |
| *TRASTP)* | (0) | (0.02) | (0) | (0) | (0.55) | (0) |
| *PLA* | 0.796 | 0.23 | 0.05 | 0.048 | 0.016 | 0.024 |
| *LFBU* | 22 | 45 | 25 | 40 | 40 | 40 |
| *LFTRA* | 140 | 400 | 140 | 500 | 500 | 500 |
| *LFP* | 0.5 | 0.9 | 0.6 | 0.6 | 0.8 | 0.75 |
| *UMT* | 0.034 | 0.6 | 0.3 | 0.7 | 0.67 | 0.7 |
| *(UMTE)* | (0.4) | (0.8) | (0.4) | (0.05) | (0.03) | (0.02) |
| *LFMTB* | 17.6 | 40 | 20 | 50 | 50 | 50 |
| *LFMTE* | 20.5 | 50 | 30 | 60 | 60 | 60 |
| Group 3.2g: Specific Energy Consumption of Passenger Transportation Modes | | | | | | |
| *GIC* | 14 | 12 | 9 | 9 | 9 | 11.5 |
| *GUC* | 19.6 | 14 | 11 | 12 | 12 | 14.5 |
| *ELUC* | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| *DBU* | 39 | 35 | 40 | 40 | 40 | 40 |
| *DTRAP* | 42,790 | 22,750 | 20,000 | 20,000 | 20,000 | 20,000 |
| *DPLA* | 691 | 800 | 700 | 700 | 700 | 700 |
| *DMT* | 50 | 40 | 60 | 60 | 60 | 60 |
| *ELMT* | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 |

*Values in parentheses are to be interpreted as fractions of the preceding category.

Specifically, the values of these parameters for Region I are based on the estimates made by Lapillonne (1978b) for the US from data given in US (1976b), FEA (1974b), SRI (1972), SPP (1975), and Hirst and Jackson (1977), Beller (1975), Salter et al. (1976), and on additional data given for Canada in WAES (1976). The corresponding estimates for Region III were made by extrapolation from the information in some Region III countries given in CEC (1978), Lapillonne (1978c), WAES (1976), Foell et al. (1979), and by comparison with the values found for Region I – taking into account similarities and differences in lifestyles and technology as described in various comparative studies between the US and Japan, US and FRG, and US and Sweden in Doernberg (1977), Goen (1975), and Schipper and Lichtenberg (1976), respectively. For Region II, some

TABLE 8 Base year data/inputs *(continued)*.

| | Region | | | | | |
|---|---|---|---|---|---|---|
| Variable | I | II | III | IV | V | VI |
| *Group 3.3: Household and Service Sector* | | | | | | |
| Group 3.3a: Important Constants/Initial Values | | | | | | |
| *DD* | 2,600 | 4,000 | 2,200 | 1,200 | 300 | 500 |
| *DWSH, ARSH* | 1 | 1 | 1 | 0.25 | 0.15 | 1 |
| *DW-75* | 79.4 | 98 | 187 | 62.6 | 271.4 | 25.3 |
| *SHDWO* (1) | 23,500 | 17,750 | 17,000 | 5,000 | 0 | 2,700 |
| *SHDWO* (2) | 12,800 | 11,500 | 11,000 | 3,500 | 0 | 1,800 |
| *SHDWO* (3) | 9,600 | 6,300 | 4,000 | 1,250 | 450 | 900 |
| *TAREA-75* | 2,720 | 1,500 | 3,000 | 600 | 1,250 | 180 |
| *CPLSER* | 1.2 | 1.028 | 1.2 | 1.534 | 1.536 | 0.824 |
| *HAREAO* | 290 | 220 | 135 | 50 | 15 | 25 |
| *BYRNCF* | a | 47.5 | a | 117 | 370 | 10.5 |
| Group 3.3b: Other Factors Determining Present Useful Energy Consumption | | | | | | |
| *COOKDW* | 1,000 | 1,000 | 1,100 | 1,600 | 1,000 | 1,600 |
| *DWHW* | 1 | 0.6 | 0.7 | 0.2 | 0.1 | 0.6 |
| *HWCAP* | 1,500 | 700 | 700 | 400 | 40 | 60 |
| *DWAC* | 0.39 | 0 | 0 | 0 | 0 | 0.01 |
| *ACDW* | 4,472 | 2,000 | 3,000 | 1,500 | 1,500 | 2,000 |
| *ELAPDW* | 3,850 | 880 | 1,950 | 700 | 50 | 200 |
| *PREDW* (1) | 0.48 | 0.05 | 0.1 | 0.08 | 0 | 0.01 |
| *PREDW* (2) | 0.32 | 0.35 | 0.2 | 0.16 | 0 | 0.05 |
| *PREDW* (3) | 0.2 | 0.6 | 0.7 | 0.56 | 0.35 | 0.4 |
| *AREAH* | 0.8 | 1 | 0.7 | 0.8 | 0.35 | 0.7 |
| *ELARO* | 120 | 40 | 40 | 25 | 15 | 15 |
| *AREAAC* | 0.55 | 0 | 0.05 | 0.05 | 0 | 0.04 |
| *ACAREA* | 70 | 70 | 70 | 70 | 70 | 70 |
| *EFFAC* | 2 | 2 | 2 | 2 | 2 | 2 |
| Group 3.3c: Factors Relevant for Projection of Useful Energy Consumption | | | | | | |
| *DEMDE* | not applicable for base year | | | | | |
| *NEWDW* (1) | | | | | | |
| *NEWDW* (2) | | | | | | |
| *NEWDW* (3) | | | | | | |
| *DWS* (1) | | | | | | |
| *DWS* (2) | | | | | | |
| *DWS* (3) | | | | | | |
| *K* (1) | | | | | | |
| *K* (2) | | | | | | |
| *K* (3) | | | | | | |
| *ISO* (1) | 0 | 0 | 0 | 0 | 0 | 0 |
| *ISO* (2) | 0 | 0 | 0 | 0 | 0 | 0 |
| *ISO* (3) | 0 | 0 | 0 | 0 | 0 | 0 |
| *AREAL* | not applicable for base year | | | | | |
| *DEMAR* | | | | | | |
| *HAREAN* | | | | | | |
| *ELARN* | | | | | | |
| *ISOSV* | 0 | 0 | 0 | 0 | 0 | 0 |

a: Noncommercial fuels are not considered in Regions I and III.

TABLE 8 Base year data/inputs *(continued)*.

| | Region | | | | | |
|---|---|---|---|---|---|---|
| Variable | I | II | III | IV | V | VI |
| Group 3.3d: Penetration of Alternative Energy Sources** | | | | | | |
| *ELP.H.SH* | 0.12 | 0 | 0.04 | 0.01 | 0.01 | 0.01 |
| *ELP.H.HW* | 0.3 | 0.07 | 0.24 | 0.01 | 0.01 | 0.01 |
| *ELP.H.CK* | 0.47 | 0.15 | 0.36 | 0.005 | 0 | 0 |
| *ELP.S.TH* | 0.05 | 0 | 0.04 | 0.01 | 0.3 | 0.01 |
| *(HPHS)* | (0) | (0) | (0) | (0) | (0) | (0) |
| *EFFHPR* | 2 | 2 | 2 | 2 | 2 | 2 |
| *DHPH* | 0 | 0.467 | 0 | 0 | 0 | 0 |
| *SPSH** | 0 | 0 | 0 | 0 | 0 | 0 |
| *FDSHS* | 0.7 | 0.4 | 0.5 | 0.8 | 0.8 | 0.8 |
| *SPHW* | 0 | 0 | 0 | 0 | 0 | 0 |
| *FDHWS* | 0.7 | 0.6 | 0.7 | 0.8 | 0.8 | 0.8 |
| *PLB* | 0.3 | 0.3 | 0.3 | 0.3 | 0.7 | 0.7 |
| *SPSV** | 0 | 0 | 0 | 0 | 0 | 0 |
| *FDHS* | 0.7 | 0.4 | 0.55 | 0.8 | 0.8 | 0.8 |
| *CHGNCF* | a | 1 | a | 1 | 1 | 1 |
| Group 3.3e: Fossil Fuel Efficiencies (relative to electricity) | | | | | | |
| *EFF.H.SH* | 0.63 | 0.59 | 0.63 | 0.6 | 0.5 | 0.6 |
| *EFF.H.HW* | 0.57 | 0.49 | 0.57 | 0.55 | 0.5 | 0.55 |
| *EFF.HCK* | 0.41 | 0.4 | 0.51 | 0.5 | 0.5 | 0.5 |
| *EFF.S.TH* | 0.7 | 0.59 | 0.7 | 0.65 | 0.55 | 0.6 |
| *EFFNCF* | a | 0.3 | a | 0.075 | 0.075 | 0.075 |

a; Noncommercial fuels are not considered in Regions I and III.
*Only relevant for post-1975 buildings.
**Values in parentheses are to be interpreted as fractions of the preceding category.

values were established from UN (1977b), ECE (1978a), ECE (1978b), CMEA (1976), and USSR (1976). Others were derived by comparison with Regions I and III and by cross-checking against the useful energy balance by process and energy source given for the USSR in Vigdorchik (1976), against the final energy consumption statistics given in ECE (1977), Melentiev (1977) and Petro Studies (1978), and against typical efficiencies given in Eurostat (1978), and Beschinsky and Kogan (1976).

For the developing regions, our estimates were based on the geographical locations of these regions, sizes of dwellings in various countries (IBRD 1976), scattered information on the pattern of energy use in the domestic sector and on the sectoral distribution of energy consumption in various countries, (e.g., Makhijani and Poole 1975, Parikh 1978, McGranahan and Taylor 1977, WAES 1976, Vieira 1978, Parikh 1976, Henderson 1975, Revelle 1976, Pakistan 1977, Elshafei 1978)*; discussions with persons from these regions, and comparison with data for other regions.

The values for *DW-75* (stock of dwellings in 1975) listed in Table 8 correspond to the data on population (*PO*) and average household size (*CAPH*). The value of *CPLSER* is determined on the basis of the value of *PYSER* (service sector share of GDP) and *PLSER*

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*Some useful information is algo given in Cecelski et al. (1979).

(fraction of labor force employed in the service sector): *CPLSER* = ln PLSER/ln *PYSER*. Information on the share of the service sector in the labor force was derived from the data in IBRD (1976), CMEA (1976), and ILO (1976).

Parameter *TAREA-75* corresponds to the service sector area in 1975. For Regions I and III, it represents the area of establishments related to trade and catering, business and social, and governmental services. For other regions, this definition was not applied due to the complete lack of data. Instead the values used for this parameter are, in combination with those of some other parameters, only a way to conceptualize the present energy requirements of the service sector.

The parameters in Group 3c of Table 8 are intended exclusively for projections and do not serve to describe the pattern of energy consumption in the base year.

## 5.2 Detailed Scenario Assumptions

The projection of final energy demand in the two IIASA scenarios is based on the formulation of detailed scenarios describing plausible evolutions of the variable parameters of MEDEE-2 listed in Appendix B. There is no universally accepted method for projecting the evolution of various socioeconomic indicators and related technological parameters over a period of several decades. The econometric approach based on extrapolations from past trends usually works well for short-term projections, but cannot be usefully applied over such long intervals. Fifty years is a short period in the history of mankind, but a fairly long time when one considers that in such a period certain economies will probably change their status from *developing* countries to *developed* countries. Some others may be forced to substantially reorientate their economic structures and the lifestyles of their populations in the face of a growing scarcity of natural resources (including energy), and under tightening environmental constraints.

In our opinion, the past trends, although useful guidelines, cannot be relied upon to make medium- to long-term projections in a rapidly changing world situation. Also there is an acute shortage of disaggregated relevant data; sufficiently detailed data are available only for a few countries (mostly developed) and, even then, such data have been compiled only in recent years. The approach followed here is, therefore, one of scenario assumptions – developed on the basis of judgments guided by past trends, interregional and intercountry comparisons whenever appropriate, estimated relationships reflecting the interdependence between various economic and social activities, and estimated prospects of technological developments. Of course, these scenario assumptions and the resulting sectoral and subsectoral energy demand projections are not deterministic; they should simply be considered as guidelines for understanding the nature of future energy demand.

The detailed scenario assumptions described in this section are the final set of MEDEE-2 inputs we arrived at after going through the iterations of the IIASA modeling loop described earlier (see Section 1). In the final stages of these iterations, the energy demand – total as well as for some broad sectors, such as transportation, household, agriculture, and industry – was also analyzed (Chant 1982) in terms of the elasticities implied – energy price elasticity, income elasticity, and elasticity of substitution – in order to ensure consistency of the aggregate results.

In Tables 9.1–9.3, the values of variable scenario parameters of MEDEE-2 used in the present assessment are listed for the years 2000 and 2030, along with those for 1975. The parameters are presented in several groups to aid understanding of the assumed variations of related parameters within each region, and also to allow interregional comparisons. (Although the values for the intermediate years 1985 and 2015 were also specified in the actual model runs, for the sake of brevity they are not listed here.) We continue with some general comments about the considerations underlying the assignment of specific values to the parameters in these different groups.

### *5.2.1 Demography* (Table 9.1)

The parameter projections in this group are based on Keyfitz (1977) and on extrapolation of past trends and the available UN projections for the next 10 to 25 years (UN 1974, 1976b).

### *5.2.2 Macroeconomics* (Table 9.2)

In order to project the GDP formation structure and the composition of the value added by manufacturing industries for the developing regions (IV, V, VI), we have obtained guidance from the observed evolution patterns in the historical data, 1960–75, for a number of countries and groups of countries at different stages of development (UN 1977b, c). The analysis of past data, 1950–70, for several countries made by Chenery and Syrquin (1975), and the short-term development plans of a few countries have also provided information.

The main features of the assumptions concerning GDP formation in these regions are the following: the share of agriculture decreases while still allowing a slow gradual improvement in per capita agricultural GDP with increasing per capita total GDP; the share of manufacturing increases, the increase being relatively higher in the High scenario than in the Low scenario; and the service sector share increases in Regions V and VI (where it was quite low in the base year), but decreases slightly in Region IV. The mining sector contributes only 2–3 percent to the GDP of Region IV and V, whereas its share in the GDP of Region VI is projected to decrease from 51 percent in 1975 to 9 percent in the High scenario and about 18 percent in the Low scenario by 2030. The value added by the mining sector in this region is mainly governed by the oil and gas extraction activities; it has been adjusted accordingly in each scenario to correspond to the envisaged production rate necessary for meeting both the domestic consumption and the export demand. It is also assumed that Region VI will undergo major industrialization within the next 10 to 25 years with the help of its oil revenues. With respect to the composition of the manufacturing industries, our projections are based on the hypothesis that the countries at a low level of industrial development have a high share of consumer goods industries, but as the industrial infrastructure develops, more emphasis is placed first on expanding the basic material and later on promoting the sophisticated machinery and equipment industries. This hypothesis is based on the observed pattern of manufacturing activities in various countries at different stages of development.

The situation is different in the developed Regions I and III. Here the GDP formation structure, as it appears on the aggregated level considered in MEDEE-2, remained practically unchanged during the period 1960–75, whereas in Region II the only significant

TABLE 9.1 Detailed scenario assumptions – demography (Group 1).

| | | 2000 | | 2030 | | | 2000 | | 2030 | | | 2000 | | 2030 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | 1975 | Low | High | Low | High | 1975 | Low | High | Low | High | 1975 | Low | High | Low | High |
| | *Region I* | | | | | *Region II* | | | | | *Region III* | | | | |
| *PO* | 237 | 284 | | 315 | | 363 | 436 | | 480 | | 560 | 680 | | 767 | |
| *PLF* | 0.64 | 0.64 | | 0.64 | | 0.64 | 0.64 | | 0.64 | | 0.63 | 0.65 | | 0.65 | |
| *PARTLF* | 0.69 | 0.69 | 0.75 | 0.69 | 0.8 | 0.61 | 0.66 | 0.7 | 0.7 | 0.8 | 0.72 | 0.75 | 0.77 | 0.77 | 0.8 |
| *POLC* | 0.64 | 0.635 | | 0.625 | | 0.42 | 0.3 | | 0.2 | | 0.51 | 0.48 | | 0.45 | |
| *PRUR** | 0.24 | 0.14 | | 0.07 | | 0.41 | 0.25 | | 0.12 | | 0.29 | 0.18 | | 0.08 | |
| *CAPH* | 2.98 | 2.48 | | 2.24 | | 3.7 | 3 | | 2.7 | | 3 | 2.72 | | 2.56 | |
| | *Region IV* | | | | | *Region V* | | | | | *Region VI* | | | | |
| *PO* | 319 | 575 | | 797 | | 1,422 | 2,528 | | 3,550 | | 133 | 247 | | 353 | |
| *PLF* | 0.542 | 0.623 | | 0.69 | | 0.538 | 0.616 | | 0.694 | | 0.523 | 0.608 | | 0.698 | |
| *PARTLF* | 0.59 | 0.59 | | 0.59 | | 0.708 | 0.708 | | 0.708 | | 0.512 | 0.512 | | 0.512 | |
| *POLC* | 0.63 | 0.47 | | 0.31 | | 0.87 | 0.77 | | 0.56 | | 0.71 | 0.55 | | 0.35 | |
| *PRUR** | 0.40 | 0.25 | | 0.15 | | 0.78 | 0.66 | | 0.45 | | 0.55 | 0.38 | | 0.18 | |
| *CAPH* | 5.1 | 4.8 | | 4.15 | | 5.24 | 4.8 | | 4.15 | | 5.25 | 4.9 | | 4.35 | |

*The values for this variable do not directly affect the calculations of the version of the MEDEE-2 model used for the present assessment, but they are used for projecting the evolution of other variables, outside the model calculations.

NOTE: See definition of variables in Appendix B, Part 2.

TABLE 9.2 Detailed scenario assumptions – macroeconomics (Group 2).

| | | 2000 | | 2030 | | | 2000 | | 2030 | | | 2000 | | 2030 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | 1975 | Low | High | Low | High | 1975 | Low | High | Low | High | 1975 | Low | High | Low | High |
| | *Region I* | | | | | *Region II* | | | | | *Region III* | | | | |
| *Y* | 1,670 | 3,049 | 4,126 | 4,170 | 7,926 | 930 | 2,420 | 2,729 | 4,713 | 7,658 | 2,385 | 4,452 | 5,999 | 6,656 | 11,693 |
| *PYAG* | 0.028 | 0.023 | 0.021 | 0.02 | 0.015 | 0.107 | 0.086 | 0.074 | 0.07 | 0.04 | 0.058 | 0.044 | 0.045 | 0.03 | 0.025 |
| *PYB* | 0.041 | 0.044 | 0.043 | 0.046 | 0.045 | 0.079 | 0.08 | 0.075 | 0.08 | 0.07 | 0.075 | 0.073 | 0.071 | 0.07 | 0.065 |
| *PYMIN** | 0 | | | | | 0 | | | | | 0 | | | | |
| *PYMAN* | 0.245 | 0.24 | 0.223 | 0.238 | 0.207 | 0.382 | 0.335 | 0.337 | 0.3 | 0.29 | 0.336 | 0.317 | 0.313 | 0.297 | 0.281 |
| *PYEN* | 0.038 | | | | | 0.042 | 0.046 | | 0.05 | | 0.046 | 0.05 | 0.049 | 0.053 | 0.05 |
| *PYSER* | 0.648 | 0.655 | 0.675 | 0.658 | 0.695 | 0.39 | 0.453 | 0.468 | 0.5 | 0.55 | 0.485 | 0.516 | 0.522 | 0.55 | 0.58 |
| *PVAIG* | 0.248 | 0.237 | 0.232 | 0.232 | 0.212 | 0.233 | 0.222 | 0.23 | 0.217 | 0.227 | 0.33 | 0.312 | 0.311 | 0.294 | 0.282 |
| *PVAM* | 0.432 | 0.458 | 0.47 | 0.47 | 0.517 | 0.476 | 0.514 | 0.521 | 0.53 | 0.568 | 0.42 | 0.445 | 0.46 | 0.471 | 0.512 |
| *PVAC* | 0.32 | 0.305 | 0.298 | 0.298 | 0.271 | 0.291 | 0.264 | 0.249 | 0.253 | 0.205 | 0.25 | 0.243 | 0.23 | 0.235 | 0.206 |
| *I*** | 0.18 | 0.195 | | 0.21 | | 0.3 | 0.265 | 0.29 | 0.25 | 0.28 | 0.25 | | | | |
| *P*** | 0.65 | 0.625 | | 0.59 | | 0.45 | 0.52 | 0.499 | 0.55 | | 0.58 | | | | |
| *PCDG*** | 0.19 | 0.21 | 0.22 | 0.23 | 0.25 | 0.1 | 0.135 | 0.139 | 0.15 | 0.18 | 0.1 | 0.131 | 0.15 | 0.16 | 0.02 |
| *PCNDG*** | 0.42 | 0.38 | 0.36 | 0.35 | 0.3 | 0.6 | 0.53 | 0.502 | 0.5 | 0.4 | 0.56 | 0.503 | 0.47 | 0.45 | 0.38 |
| *PCSER*** | 0.39 | 0.41 | 0.42 | 0.42 | 0.45 | 0.3 | 0.335 | 0.359 | 0.35 | 0.42 | 0.34 | 0.366 | 0.38 | 0.39 | 0.42 |
| | *Region IV* | | | | | *Region V* | | | | | *Region VI* | | | | |
| *Y* | 340 | 918 | 1,272 | 2,229 | 3,569 | 340 | 924 | 1,207 | 1,995 | 3,488 | 190 | 643 | 900 | 1,310 | 2,918 |
| *PYAG* | 0.122 | 0.095 | 0.076 | 0.065 | 0.046 | 0.361 | 0.296 | 0.255 | 0.232 | 0.162 | 0.07 | 0.05 | 0.041 | 0.04 | 0.023 |
| *PYB* | 0.057 | 0.06 | | 0.07 | | 0.058 | 0.06 | | 0.06 | | 0.065 | 0.106 | | 0.091 | 0.076 |
| *PYMIN** | 0.025 | 0.02 | | 0.02 | | 0.015 | 0.018 | | 0.022 | | 0.51 | 0.155 | 0.2 | 0.175 | 0.09 |
| *PYMAN* | 0.248 | 0.285 | 0.304 | 0.291 | 0.33 | 0.166 | 0.2 | 0.223 | 0.228 | 0.258 | 0.078 | 0.258 | 0.242 | 0.25 | 0.273 |
| *PYEN* | 0.025 | 0.035 | 0.036 | 0.049 | 0.05 | 0.016 | 0.026 | 0.028 | 0.038 | 0.042 | 0.007 | 0.024 | 0.023 | 0.028 | |
| *PYSER* | 0.523 | 0.505 | 0.504 | 0.505 | 0.484 | 0.384 | 0.4 | 0.417 | 0.42 | 0.456 | 0.27 | 0.407 | 0.388 | 0.416 | 0.51 |
| *PVAIG* | 0.308 | 0.344 | 0.356 | 0.364 | 0.352 | 0.264 | 0.297 | 0.319 | 0.311 | 0.367 | 0.2 | 0.35 | | 0.4 | 0.35 |
| *PVAM* | 0.264 | 0.333 | 0.356 | 0.386 | 0.42 | 0.176 | 0.22 | 0.242 | 0.256 | 0.3 | 0.1 | 0.12 | 0.15 | 0.2 | 0.4 |
| *PVAC* | 0.429 | 0.322 | 0.289 | 0.25 | 0.227 | 0.56 | 0.484 | 0.44 | 0.433 | 0.333 | 0.7 | 0.53 | 0.5 | 0.4 | 0.25 |
| *I*** | 0.23 | | | | | 0.2 | 0.22 | | 0.23 | | 0.215 | 0.35 | | 0.3 | 0.25 |
| *P*** | 0.7 | 0.65 | 0.64 | 0.63 | 0.61 | 0.71 | 0.67 | | 0.65 | | 0.325 | 0.445 | | 0.47 | 0.55 |
| *PCDG*** | 0.1 | 0.11 | 0.12 | 0.12 | 0.14 | 0.07 | 0.08 | 0.09 | 0.1 | 0.13 | 0.1 | 0.12 | 0.13 | 0.13 | 0.15 |
| *PCNDG*** | 0.6 | 0.57 | 0.55 | 0.54 | 0.51 | 0.73 | 0.7 | 0.68 | 0.67 | 0.61 | 0.6 | 0.55 | 0.555 | 0.55 | 0.515 |
| *PCSER*** | 0.3 | 0.32 | 0.33 | 0.34 | 0.35 | 0.2 | 0.22 | 0.23 | 0.24 | 0.26 | 0.3 | 0.33 | 0.315 | 0.32 | 0.335 |

*For Regions I, II, and III, minings of coal, oil, and gas is included in the energy sector and that of other materials is included under manufacturing of bas materials (see definition of sectors in Appendix C).

**The values for these variables do not directly affect the calculations of the version of the MEDEE 2 model used for the present assessment, but they a for projecting the evolution of other variables, outside the model calculations.

change in this period was a decline of the agricultural share* from 32 to 15 percent and an increase in the industry (mining, manufacturing, and energy sectors) share from 41 to 57 percent.

The shifts in the structure of GDP formation assumed in the light of a retarding overall economic growth can be qualitatively described as follows. For Region I, the service sector share is assumed to increase slightly and the manufacturing share is assumed to decrease by roughly the same amount (the change is insignificant in the Low scenario). GDP formation structures assumed for Regions II and III gradually shift toward the pattern of Region I as these regions proceed to a higher level of economic development. All three regions are assumed to give higher emphasis to the development of machinery and equipment industries than to the basic materials and consumer goods industries. Only minor shifts are assumed in the GDP shares of construction and energy sectors in all the regions. The share of agriculture in GDP is assumed to decrease in all three regions in line with past trends. However, this decrease is large only in the case of Region II, whose share was large in the base year and which is projected to have a higher overall economic growth in each scenario than either of the two other developed regions.

### *5.2.3 Energy Consumption in Sectors*

#### *I Industry* (Table 9.3.1)

We have assumed that there will not be any significant changes in the energy intensity of agriculture and construction in the developed Regions I and III. This is because it was difficult to estimate the net effect of two oppositely acting factors: the likely improvements in the efficiencies of equipment used in these sectors, and a probable further, albeit small, increase in the mechanization of such activities. In Region II, the energy intensity of agriculture and construction activities are assumed to decrease slightly, with the sometimes inefficient use of the relatively heavy equipment currently employed. In the long term, therefore, efficiency improvements are expected to more than counterbalance the effect of increasing mechanization. As the mining sector in Regions I, II, and III is not considered separately but as part of the manufacturing and energy sector activities, its energy intensity is not given explicitly.

At present, agricultural activities in all the developing regions are largely carried out using traditional methods based on human and animal labor. The same is true for construction and nonpetroleum mining activities, at least in Regions V and VI. One may expect increasing mechanization of such activities with further development and a correspondingly greater demand for quality and quantity of sectoral products. In the case of agriculture, for example, considerable and rather rapid mechanization is necessary to obtain higher outputs from the limited resources of arable land required to supply a rapidly growing population with more and better food. The projected changes in energy intensity are based on our estimates of the energy requirements of field equipment (tractors and other appliances) and of irrigation water-pumping units, assuming that by 2030 agricultural

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*These shares are based on values of GDP which do not include nonproductive services, e.g., social and administrative services. If the contribution of such nonproductive services is also included in GDP the shares of sectors will be somewhat different. It was estimated that the inclusion of nonproductive services in GDP of 1975 would lower the shares of agriculture and manufacturing by a factor of 1.35, i.e., to 11 and 38 percent, respectively. These numbers can be compared to the GDP shares in market economy regions.

TABLE 9.3.1 Detailed scenario assumptions – industry.

| | | 2000 | | 2030 | | | 2000 | | 2030 | | | 2000 | | 2030 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | 1975 | Low | High | Low | High | 1975 | Low | High | Low | High | 1975 | Low | High | Low | High |
| Change of energy intensity of agriculture/construction/mining (Group 3.1c) | | | | | | | | | | | | | | | |
| | *Region I* | | | | | *Region II* | | | | | *Region III* | | | | |
| *CH.AGR.MF* | 1 | 1 | | 1 | | 1 | 0.92 | 0.9 | 0.85 | 0.8 | 1 | 1 | | 1 | |
| *CH.AGR.EL* | 1 | 1 | | 1 | | 1 | 0.97 | 0.95 | 0.95 | 0.9 | a | | | | |
| *CH.AGR.TH* | a | | | | | a | | | | | a | | | | |
| *CH.CON.MF* | 1 | 1 | | 1 | | 1 | 0.92 | 0.9 | 0.85 | 0.8 | 1 | 1 | | 1 | |
| *CH.CON.EL* | a | | | | | 1 | 0.97 | 0.95 | 0.95 | 0.9 | a | | | | |
| *CH.CON.TH* | a | | | | | a | | | | | a | | | | |
| *CH.MIN.MF* | b | | | | | b | | | | | b | | | | |
| *CH.MIN.EL* | b | | | | | b | | | | | b | | | | |
| *CH.MIN.TH* | b | | | | | b | | | | | b | | | | |
| | *Region IV* | | | | | *Region V* | | | | | *Region VI* | | | | |
| *CH.AGR.MF* | 1 | 5.5 | | 10 | | 1 | 5.5 | | 10 | | 1 | 4.5 | | 7 | |
| *CH.AGR.EL* | 1 | 5.5 | | 10 | | 1 | 5.5 | | 10 | | 1 | 8 | | 20 | |
| *CH.AGR.TH* | a | | | | | a | | | | | a | | | | |
| *CH.CON.MF* | 1 | 0.85 | | 0.75 | | 1 | 5.5 | | 10 | | 1 | 4.5 | | 6 | |
| *CH.CON.EL* | 1 | 1 | | 1 | | a | | | | | a | | | | |
| *CH.CON.TH* | a | | | | | a | | | | | a | | | | |
| *CH.MIN.MF* | 1 | 0.85 | | 0.75 | | 1 | 5.5 | | 10 | | a | | | | |
| *CH.MIN.EL* | 1 | 1 | | 1 | | a | | | | | a | | | | |
| *CH.MIN.TH* | a | | | | | a | | | | | 1 | 1 | | 1 | |
| Change of energy intensity of manufacturing industries (Group 3.1d) | | | | | | | | | | | | | | | |
| | *Region I* | | | | | *Region II* | | | | | *Region III* | | | | |
| *CH.MAN.MF* | 1 | | | | | a | | | | | a | | | | |
| *CH.MAN.EL* | 1 | 0.93 | | 0.9 | | 1 | 0.94 | 0.93 | 0.9 | 0.85 | 1 | 0.93 | | 0.9 | |
| *CH.MAN.US* | 1 | 0.87 | 0.86 | 0.8 | 0.75 | 1 | 0.8 | 0.75 | 0.6 | 0.5 | 1 | 0.87 | 0.85 | 0.8 | 0.75 |
| | *Region IV* | | | | | *Region V* | | | | | *Region VI* | | | | |
| *CH.MAN.MF* | a | | | | | a | | | | | a | | | | |
| *CH.MAN.EL* | 1 | 1 | | 1 | | 1 | 1 | | 1 | | 1 | 0.81 | | 0.75 | |
| *CH.MAN.US* | 1 | 0.85 | | 0.75 | | 1 | 0.85 | | 0.75 | | 1 | 0.6 | | 0.5 | |

Penetration of alternative energy sources and efficiencies (Group 3.1f)

| | *Region I* | | | *Region II* | | | *Region III* | | |
|---|---|---|---|---|---|---|---|---|---|
| *ELPIND* (4)* | 0 | 0.07 | 0.1 | 0 | 0.03 0.05 | 0.05 0.1 | 0 | 0.03 | 0.05 |
| *(HPI)* | (0) | (0.33) | (0.5) | (0) | (0) | (0) | (0) | (0.33) | (0.5) |
| *FFFHPI* | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| *IDH* | 0 | 0 | 0 | 0.69 | 0.8 | 0.85 | 0 | 0.07 | 0.15 |
| *SPLT* | 0 | 0.07 | 0.15 | 0 | 0.04 | 0.1 | 0 | 0.07 | 0.15 |
| *SPHT* | 0 | 0.02 | 0.05 | 0 | 0.01 | 0.03 | 0 | 0.02 | 0.05 |
| *FIDS* | 0.7 | 0.7 | 0.7 | 0.3 | 0.3 | 0.3 | 0.7 | 0.7 | 0.7 |
| *ICOGEN* | 0 | 0.33 | 0.5 | 0 | 0 | 0 | 0.3 | 0.45 | 0.6 |
| *EFFCOG* | c | 0.72 | 0.75 | c | | | 0.65 | 0.72 | 0.75 |
| *HELRAT* | c | 5 | 5 | c | | | 5 | 5 | 5 |
| *EFFIND* (4)** | 0.65 | 0.72 0.74 | 0.75 0.8 | 0.605 | 0.7 | 0.8 | 0.65 | 0.72 | 0.75 0.08 |

| | *Region IV* | | | *Region V* | | | *Region VI* | | |
|---|---|---|---|---|---|---|---|---|---|
| *ELPIND* (4)* | 0 | 0.03 | 0.1 | 0 | 0.01 | 0.04 | 0 | 0.03 | 0.1 |
| *(HPI)* | (0) | (0.04) | (0.2) | (0) | (0.01) | (0.1) | (0) | (0.04) | (0.2) |
| *EFFHPI* | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| *IDH* | 0 | 0.03 | 0.12 | 0 | 0 | 0 | 0 | 0.03 | 0.12 |
| *SPLT* | 0 | 0.05 | 0.3 | 0 | 0.05 | 0.3 | 0 | 0.05 | 0.3 |
| *SPHT* | 0 | 0.01 | 0.1 | 0 | 0.01 | 0.1 | 0 | 0.01 | 0.1 |
| *FIDS* | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| *ICOGEN* | 0 | 0.05 | 0.2 | 0 | 0.04 | 0.15 | 0 | 0.15 | 0.25 |
| *EFFCOG* | c | 0.68 | 0.75 | c | 0.68 | 0.75 | c | 0.68 | 0.75 |
| *HELRAT* | c | 5 | 5 | c | 5 | 5 | c | 5 | 5 |
| *EFFIND* (4)** | 0.6 | 0.63 | 0.7 | 0.5 | 0.54 | 0.63 | 0.55 | 0.66 | 0.7 |

Coke use in iron and steel industry (Group 3.1h)

| | *Region I* | | | *Region II* | | | *Region III* | | |
|---|---|---|---|---|---|---|---|---|---|
| *BOF* | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 | 0.5 | 0.8 | 0.8 | 0.8 |
| *IRONST* | 0.97 | 0.97 | 0.97 | 0.9 | 0.9 | 0.9 | 0.97 | 0.97 | 0.97 |
| *EICOK* | 600 | 440 | 350 | 700 | 590 | 400 | 500 | 450 | 400 |

| | *Region IV* | | | *Region V* | | | *Region VI* | | |
|---|---|---|---|---|---|---|---|---|---|
| *BOF* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| *IRONST* | 0.6 | 0.7 | 0.8 | 0.95 | 0.85 | 0.8 | 1.2 | 0.9 | 0.8 |
| *EICOK* | 600 | 500 | 400 | 900 | 750 | 550 | 1000 | 500 | 400 |

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*Electricity penetration into the thermal energy market above levels reached today.

**Efficiency of fossil fuel use relative to electricity.

NOTE: Values in parentheses are to be interpreted as fractions of the preceding category.

a: Separate data were not available.

b: The corresponding requirements are accounted for elsewhere.

c: Not applicable if ICOGEN is zero.

activities in the developing regions will be mechanized to an extent comparable to the present level of mechanization in the developed regions. Mechanization is also assumed to increase in the construction activities in Regions V and VI, but to relatively lower levels than those found in the developed regions. For the mining sector, the changes assumed take into account differences in the nature of mining activities and in the working conditions in the various regions, and reflect a likely future improvement.

It may be mentioned here that there are considerable uncertainties in the base year data of energy intensity of agriculture, construction, and mining activities of almost all regions, both developed and developing. The assumed changes in the energy intensity of these sectors should, therefore, be considered as qualitative indicators of a likely trend.

MEDEE-2 considers manufacturing activities by only three broad categories: basic materials industries, machinery and equipment industries, and consumer goods (nondurable) industries. Each category covers the manufacturing of a variety of products so that its composition is not uniform for all the regions; and even within a single region the composition cannot be assumed to remain constant all the time. The energy intensity of each category is thus affected by changes in composition as well as by changes and improvements in technology. The parameters of Group 3.1d in Table 3.9.1 are intended to project the changes in energy intensity of each category covering both the above aspects.

The data on energy consumption of various manufacturing industries in different countries over the last 15–20 years reveal a gradual reduction in energy intensity over time, e.g., for US, France, FRG, Austria, see Doblin (1978), Lapillonne (1978c), Schaefer et al. (1977), Foell et al. (1979). This is, in general, due to a reduction in the use of fossil fuels (per unit of output), while the specific use of electricity (per unit of output), by most of the industries, has actually been increasing.

The past increases in the use of electricity in the developing countries were generally due to increasing automation. As automation in the developed regions has already reached a high level and as electricity prices are expected to rise in the coming years, it is assumed that the use of electricity (per unit of output) for specific purposes will also decrease in the future, although not as fast as the use of fossil fuels. In the developing regions, where automation is expected to continue to rise, the energy intensity of manufacturing activities with respect to specific uses of electricity is assumed to be constant.

The projected changes in energy intensity of manufacturing activities in various regions are based, in general, on considerations of the present status of the technology in each region, rates of increase in industrialization (high growth allows more rapid incorporation of new technologies), and the prospects of technological improvement in line with past trends.

Thermal energy requirements of industry are, at present, normally met by direct use of fossil fuels (coal, oil, gas). The only exception is Region II, where a large fraction of the industrial steam demand is supplied by district heat systems based on both cogeneration plants and large boilers. This development has been due to central planning and considerable concentration of industry into just a few industrial centers. Application of such district heat systems in Region II is expected to grow further, because of the economic use of low-grade fuels in such systems. Other regions are also expected to employ such centralized heat supply systems to some extent, even though their industries are relatively more widely scattered. Similarly, the decentralized use of cogeneration systems in industrial plants is expected to increase in Region III and to be applied in other regions. Other energy-saving technologies, such as soft solar devices and (electric) heat pumps, are generally not in use now in any region. They, too, are expected to be applied more heavily as the capital cost of such systems reduces with research and development, and mass production. Electricity use for thermal processes is assumed to increase only modestly above present-day levels; although it is a very clean, efficient and easy-to-handle form of energy, the high losses incurred in the conversion from primary fuels to secondary energy would be in conflict with the need to conserve primary fuels. Despite the penetration of alternative energy sources assumed, a large share of the thermal energy for industry will have to come from the direct use of fossil fuels even by 2030, so that improvements in efficiency of fossil fuel appear mandatory. Some such improvements have been assumed to materialize in line with past trends.

The present use of coke per ton of pig-iron produced varies considerably from country to country. So far, the lowest consumption was achieved by the Japanese steel industry where the consumption decreased to about 390 kg per ton of pig-iron in 1972 (see Doernberg 1977). However, after the oil crisis, coke consumption in Japan again increased as fuel oil injections were lowered; in 1975 the consumption was 440 kg per ton of pig-iron. Despite this short-term reversal in the trend of the Japanese steel industry, we have assumed that future technological improvement will permit reduction in coke use to about 400 kg per ton of pig-iron in the various world regions. The changes assumed for other parameters related to steel production are based on discussions with technologists and on interregional comparison.

*II Transportation* (Table 9.3.2)

The evolution of the modes of freight transportation assumed to occur in the various regions is based on consideration of past trends, regional characteristics, interregional comparison, existing infrastructure, relative costs of expanding road or railway networks, and the need to promote less energy intensive modes of transportation in the future. These essentially judgmental projections were developed in the light of the above considerations. No change has been assumed (except for Region II) in the energy intensity of various freight transportation modes. This does not mean that efficiency improvements will not occur but that their effect will largely be counterbalanced by lower capacity utilization resulting from the need for quicker service.

Data for passenger transportation in the US, 1950–74 (US 1976a), indicates that the total distance traveled per person and per year has been increasing somewhat faster than the increase in per capita private consumption expenditure. Such a rapid increase has apparently been due to the greater number of cars and the rapid expansion of air travel in recent years. With car ownership practically saturated, any further increase in the average distance traveled per person and per year will mainly depend on a further increase in air travel. This is a shift away from the past trend and toward a gradual development of saturation effects in personal travel in this region. In Regions II and III as well as in the developing regions, car ownership is still far from saturation and air travel is low. Both are expected to expand in the future, resulting in a high growth of passenger transportation activity. However, some saturation effects in Region III may become apparent toward the end of the study period. The past US trend has been taken as a general guideline for projecting passenger travel in the developed Regions II and III, although some adjustments were necessary in view of the differences in travel distances, settlement patterns, and other local conditions. As for the developing countries, intercity travel (parameter *DI*) is assumed to increase roughly in proportion to the per capita private

TABLE 9.3.2 Detailed scenario assumptions – transportation.

| | | 2000 | | 2030 | | | 2000 | | 2030 | | | 2000 | | 2030 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | 1975 | Low | High | Low | High | 1975 | Low | High | Low | High | 1975 | Low | High | Low | High |
| Distribution of freight transportation by mode (Group 3.2b) | | | | | | | | | | | | | | | |
| | *Region I* | | | | | *Region II* | | | | | *Region III* | | | | |
| *TRU* | 0.234 | 0.239 | | 0.242 | | 0.025 | 0.043 | | 0.05 | | 0.55 | 0.55 | | 0.55 | |
| *(TRUL)* | (0.15) | (0.12) | | (0.1) | | (0) | (0) | | (0) | | (0) | (0) | | (0) | |
| *FTRA* | 0.39 | 0.379 | | 0.373 | | 0.775 | 0.757 | | 0.75 | | 0.3 | 0.3 | | 0.3 | |
| *(TRAEF)* | (0) | (0) | | (0) | | (0.35) | (0.55) | | (0.8) | | (0.3) | (0.4) | | (0.5) | |
| *(TRASTF)* | (0) | (0) | | (0) | | (0.055) | (0.02) | | (0) | | (0) | (0) | | (0) | |
| *BA* | 0.164 | 0.165 | | 0.165 | | 0.05 | 0.05 | | 0.05 | | 0.1 | 0.1 | | 0.1 | |
| *PIP* | 0.212 | 0.217 | | 0.22 | | 0.15 | 0.15 | | 0.15 | | 0.05 | 0.05 | | 0.05 | |
| | *Region IV* | | | | | *Region V* | | | | | *Region VI* | | | | |
| *TRU* | 0.615 | 0.6 | | 0.56 | | 0.45 | 0.56 | | 0.6 | | 0.426 | 0.56 | | 0.51 | |
| *(TRUL)* | (0) | (0) | | (0) | | (0) | (0) | | (0) | | (0) | (0) | | (0) | |
| *FTRA* | 0.175 | 0.21 | | 0.28 | | 0.35 | 0.28 | | 0.27 | | 0.024 | 0.07 | | 0.18 | |
| *(TRAEF)* | (0.01) | (0.05) | | (0.2) | | (0.15) | (0.3) | | (0.5) | | (0.05) | (0.12) | | (0.3) | |
| *(TRASTF)* | (0) | (0) | | (0) | | (0.55) | (0.15) | | (0) | | (0) | (0) | | (0) | |
| *BA* | 0.15 | 0.13 | | 0.1 | | 0.08 | 0.08 | | 0.08 | | 0.03 | 0.04 | | 0.06 | |
| *PIP* | 0.06 | 0.06 | | 0.06 | | 0.12 | 0.08 | | 0.06 | | 0.52 | 0.33 | | 0.25 | |
| Energy intensity of freight transportation modes (Group 3.2c) | | | | | | | | | | | | | | | |
| | *Region I* | | | | | *Region II* | | | | | *Region III* | | | | |
| *DTRU* | 400 | | | | | 800 | 750 | | 700 | | 800 | | | | |
| *DTRUL* | 1,100 | | no | | | a | | | | | a | | no | | |
| *DTRAF* | 100 | | | | | 100 | 90 | | 80 | | 200 | | | | |
| *DBA* | 80 | | change | | | 100 | 90 | | 80 | | 200 | | change | | |
| *DPIP* | b | | | | | b | | | | | b | | | | |
| | *Region IV* | | | | | *Region V* | | | | | *Region VI* | | | | |
| *DTRU* | 800 | | | | | 800 | | | | | 800 | | | | |
| *DTRUL* | a | | no | | | a | | no | | | a | | no | | |
| *DTRAF* | 200 | | | | | 200 | | | | | 200 | | | | |
| *DBA* | 200 | | change | | | 200 | | change | | | 200 | | change | | |
| *DPIP* | b | | | | | b | | | | | 70 | | | | |

Distance traveled per person (Group 3.2d)

| | *Region I* | | | | | *Region II* | | | | | *Region III* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *DI*$^a$ | 10,000 | 13,340 | 13,600 | 15,000 | 17,000 | 2,650 | 4,350 | 5,000 | 5,600 | 7,500 | 7,500 | 8,800 | 10,000 | 10,000 | 12,000 |
| *DU*$^b$ | 56 | 60 | 61 | 62 | 65 | 10 | 13 | 16 | 15 | 20 | 9.7 | 15 | 18.5 | 20 | 30 |

| | *Region IV* | | | | | *Region V* | | | | | *Region VI* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *DI*$^a$ | 1,850 | 2,600 | 3,500 | 4,400 | 6,800 | 500 | 750 | 950 | 1,100 | 1,900 | 1,050 | 2,600 | 3,650 | 4,000 | 10,000 |
| *DU*$^b$ | 16.5 | 19.5 | 20.5 | 24 | 26.5 | 11 | 12.5 | 13 | 16 | 17 | 11 | 15 | 16 | 22 | 25 |

Car travel (Group 3.2e)

| | *Region I* | | | | | *Region II* | | | | | *Region III* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *CO* | 2 | 1.9 | | 1.9 | | 40 | 20 | 16 | 15 | 10 | 5.21 | 4.17 | 3.28 | 3.2 | 2.22 |
| *DIC* | 7,000 | 7,530 | 7,570 | 7,800 | 8,000 | 5,000 | 5,580 | 5,750 | 6,000 | 6,500 | 5,000 | 5,310 | 5,500 | 5,600 | 5,800 |
| *LFIC* | 2.6 | 2.6 | | 2.6 | | 3 | 3 | 2.8 | 3 | 2.6 | 2.3 | 2.3 | | 2.3 | |
| *UC* | 0.966 | 0.926 | | 0.9 | | 0.4 | 0.4 | | 0.4 | | 0.7 | 0.61 | | 0.5 | |
| *(UCE)* | (0) | (0.06) | | (0.2) | | (0) | (0.05) | | (0.2) | | (0) | (0.06) | | (0.2) | |
| *LFUC* | 1.6 | 1.68 | | 1.8 | | 2.5 | 2.5 | 2.3 | 2.5 | 2.1 | 1.5 | 1.5 | | 1.5 | |

| | *Region IV* | | | | | *Region V* | | | | | *Region VI* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *CO* | 25.64 | 13.83 | 9.98 | 6.94 | 4.34 | 268 | 113 | 87 | 46 | 26 | 59.5 | 23.7 | 16.9 | 12.6 | 5.64 |
| *DIC* | 6,300 | 7,500 | | 8,000 | | 6,700 | 7,500 | | 8,000 | | 6,000 | 7,000 | | 8,000 | |
| *LFIC* | 3.5 | 2.8 | 2.6 | 2.4 | 2.3 | 3.5 | 3.3 | 3.2 | 3 | 2.8 | 3 | 2.8 | 2.6 | 2.4 | 2.2 |
| *UC* | 0.3 | 0.35 | | 0.35 | | 0.33 | 0.35 | | 0.35 | | 0.3 | 0.4 | | 0.45 | 0.5 |
| *(UCE)* | (0) | (0.01) | | (0.05) | | (0) | (0) | | (0) | | (0) | (0.01) | | (0.05) | |
| *LFUC* | 2.5 | 2.3 | 2.2 | 2 | | 2.5 | 2.45 | 2.4 | 2.3 | 2.2 | 2 | 1.9 | 1.85 | 1.8 | 1.65 |

Public transportation (Group 3.2f)

| | *Region I* | | | | | *Region II* | | | | | *Region III* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *PBU* | 0.153 | 0.135 | 0.123 | 0.123 | 0.075 | 0.15 | 0.18 | | 0.2 | | 0.35 | 0.319 | 0.3 | 0.29 | 0.25 |
| *PTRA* | 0.051 | 0.051 | | 0.051 | 0.05 | 0.62 | 0.56 | 0.52 | 0.5 | 0.45 | 0.6 | 0.58 | 0.51 | 0.56 | 0.4 |
| *(TRAEP)* | (0.01) | (0.14) | | (0.2) | | (0.5) | (0.65) | | (0.8) | | (0.3) | (0.4) | | (0.5) | |
| *(TRASTP)* | (0) | (0) | | (0) | | (0.02) | (0) | | (0) | | (0) | (0) | | (0) | |
| *PLA* | 0.796 | 0.814 | 0.826 | 0.826 | 0.875 | 0.23 | 0.26 | 0.3 | 0.3 | 0.35 | 0.05 | 0.101 | 0.19 | 0.15 | 0.35 |
| *LFBU* | 22 | 22 | | 22 | | 45 | 35 | | 25 | | 25 | 25 | | 25 | |

TABLE 9.3.2 Detailed scenario assumptions – transportation *(continued)*.

| | | 2000 | | 2030 | | | 2000 | | 2030 | | | 2000 | | 2030 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | 1975 | Low | High | Low | High | 1975 | Low | High | Low | High | 1975 | Low | High | Low | High |
| *LFTRA* | 140 | 140 | | 140 | | 400 | 300 | | 200 | | 140 | 140 | | 140 | |
| *LFP* | 0.5 | 0.57 | | 0.6 | | 0.9 | 0.8 | | 0.7 | | 0.6 | 0.6 | | 0.6 | |
| *UMT* | 0.034 | 0.074 | | 0.1 | | 0.6 | 0.6 | | 0.6 | | 0.3 | 0.39 | | 0.5 | |
| *(UMTE)* | (0.4) | (0.47) | | (0.5) | | (0.8) | (0.8) | | (0.8) | | (0.4) | (0.4) | | (0.4) | |
| *LFMTB* | 17.6 | 17.6 | | 17.6 | | 40 | 30 | | 20 | | 20 | 20 | | 20 | |
| *LFMTE* | 20.5 | 20.5 | | 20.5 | | 50 | 40 | | 30 | | 30 | 30 | | 30 | |
| | *Region IV* | | | | | *Region V* | | | | | *Region VI* | | | | |
| *PBU* | 0.845 | 0.81 | 0.79 | 0.77 | 0.73 | 0.67 | 0.66 | 0.65 | 0.64 | 0.6 | 0.844 | 0.755 | 0.745 | 0.64 | 0.6 |
| *PTRA* | 0.107 | 0.085 | 0.09 | 0.07 | | 0.314 | 0.3 | | 0.3 | | 0.132 | 0.2 | | 0.3 | |
| *(TRAEP)* | (0.01) | (0.05) | | (0.2) | | (0.15) | (0.3) | | (0.5) | | (0.05) | (0.12) | | (0.3) | |
| *(TRASTP)* | (0) | (0) | | (0) | | (0.55) | (0.15) | | (0) | | (0) | (0) | | (0) | |
| *PLA* | 0.048 | 0.105 | 0.12 | 0.16 | 0.2 | 0.016 | 0.04 | 0.05 | 0.06 | 0.1 | 0.024 | 0.045 | 0.055 | 0.06 | 0.1 |
| *LFBU* | 40 | 38 | 35 | 30 | 26 | 40 | 39 | 38 | 35 | 30 | 40 | 35 | 34 | 30 | 25 |
| *LFTRA* | 500 | 350 | | 250 | 200 | 500 | 480 | 450 | 400 | 350 | 500 | 375 | 350 | 250 | 200 |
| *LFP* | 0.6 | 0.6 | | 0.6 | | 0.8 | 0.7 | | 0.6 | | 0.75 | 0.6 | | 0.6 | |
| *UMT* | 0.7 | 0.65 | | 0.65 | | 0.67 | 0.65 | | 0.65 | | 0.7 | 0.6 | | 0.55 | 0.5 |
| *(UMTE)* | (0.05) | (0.1) | | (0.25) | | (0.03) | (0.04) | | (0.08) | | (0.02) | (0.035) | | (0.1) | |
| *LFMTB* | 50 | 45 | 40 | 40 | 30 | 50 | 48 | 45 | 40 | 35 | 50 | 42 | 38 | 35 | 25 |
| *LFMTE* | 60 | 55 | 48 | 45 | 35 | 60 | 55 | 52 | 45 | 40 | 60 | 52 | 48 | 40 | 35 |

Specific energy consumption of passenger transportation modes (Group 3.2g)

| | *Region I* | | | | *Region II* | | | | | *Region III* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *GIC* | 14 | 6.5 | 6.2 | 6 | 12 | 9.6 | 7.5 | 8 | 6 | 9 | 8.5 | 6.2 | 6 |
| *GUC* | 19.6 | 8.9 | 8.5 | 7.6 | 14 | 11.6 | 9.5 | 10 | 8 | 11 | 10 | 8.5 | 7.5 |
| *ELUC* | 0.25 | 0.25 | 0.25 | | 0.25 | 0.25 | | 0.25 | | 0.25 | 0.25 | 0.25 | |
| *DBU* | 39 | 39 | 39 | | 35 | 33 | | 30 | | 40 | 40 | 40 | |
| *DTRAP* | 42,790 | 42,790 | 42,790 | | 22,750 | 20,000 | | 18,000 | | 20,000 | 20,000 | 20,000 | |
| *DPLA* | 691 | 565 | 500 | | 800 | 700 | | 600 | | 700 | 700 | 700 | |
| *DMT* | 50 | 50 | 50 | | 40 | 37 | | 35 | | 60 | 60 | 60 | |
| *ELMT* | 3.4 | 3.4 | 3.4 | | 3.4 | 3.4 | | 3.4 | | 3.4 | 3.4 | 3.4 | |

| | *Region IV* | | | *Region V* | | | *Region VI* | | |
|---|---|---|---|---|---|---|---|---|---|
| *GIC* | 9 | 8 | 8 | 9 | 8 | 8 | 11.5 | 8.5 | 7.5 |
| *GUC* | 12 | 10.5 | 10.5 | 12 | 10.5 | 10.5 | 14.5 | 10.7 | 9.5 |
| *ELUC* | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| *DBU* | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| *DTRAP* | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 |
| *DPLA* | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 |
| *DMT* | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| *ELMT* | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 |

NOTE: Values in parentheses are to be interpreted as fractions of the preceding category.

a: Separate data were not available.

b: Corresponding energy consumption accounted for elsewhere.

[a] Distance traveled per person *per year*, intercity (applies to the total population).

[b] Distance traveled per person *per day*, intracity (applies only to the population of large cities).

consumption expenditure. The relative increase in urban travel is assumed to be lower than that in intercity travel for all the regions, except for Region III where the current trend of suburban expansion is expected to continue.

Among the parameters related to car travel (Group 3.2e), car ownership (i.e., the inverse of parameter *CO*) is assumed to increase in the developing regions in proportion to both GDP per capita and the fraction of population living in urban areas. Relatively lower growth rates of car ownership are assumed for the developed regions where saturation effects are expected to play a varying role. The share of cars in urban travel is assumed to decrease or remain constant in the developed regions due to the promotion of mass transit systems. In the developing regions, the increase in car ownership would favor a heavier use of cars for urban travel, but road congestion in the overcrowded cities would have the opposite effect. Thus a significant increase in the use of cars for urban travel is assumed only for Region VI, where enough resources are available to modernize the road network. Load factors of cars are expected to decrease with increasing car ownership almost everywhere, particularly in the developing regions. Some use of electric cars for urban travel, to varying extents in different regions, is also envisaged in the future.

The scenario assumptions about various modes of intercity and urban travel (Groups 3.2e and 3.2f) are based on considerations similar to those discussed in connection with modes of freight transportation. Additional factors, such as personal convenience, flexibility, and speed of travel were also accounted for by the mass transit modes chosen; the share of airplanes in intercity travel is assumed to increase everywhere. The share of intercity buses, on the other hand, is expected to decrease in all regions except in Region II. The load factors of mass transit modes (except for airplanes) are assumed to remain constant in Regions I and III, where they are already quite low. In all the other regions, they are assumed to decrease from the present high level to relatively more comfortable standards as the service will certainly be improved with further development in these regions.

The specific energy consumption of cars is expected to go down in all the regions, due to rising gasoline prices and the initiation of fuel economy standards in several countries. The assumed drop in future fuel consumption is most strongly pronounced in Region I, where present automobile fuel consumption is very high, compared to that in other regions. Significant reductions in the energy intensity of airplanes are also expected in Regions I and II, in view of the importance of domestic air travel in these regions. Such reductions in other regions, though probable, have not been taken into account, since the share of air travel in intercity travel in Regions III through VI is much smaller than in Regions I and II. The specific energy consumption of other passenger transport modes in Regions I and III and the respective load factors were held constant in the present assessment. One should expect vehicle efficiencies to improve and the load factors to decline further; since the two effects would thus partly balance each other they were not considered separately. In the developing regions a trend towards larger vehicles was assumed to offset improvements in vehicle efficiencies. In Region II, improvements in these modes were considered after discussions with experts from this region, where reliance on mass transit and trains in particular, counts more heavily than in the other regions.

*III Households and Services* (Table 9.3.3)

As mentioned in Part III of Section 5.1.3, a large number of parameters are used in MEDEE-2 to conceptualize the likely evolution of energy consumption associated with various activities in the household/service sector. The scenario assumptions concerning

TABLE 9.3.3 Detailed scenario assumptions – household/service sector.

| | | 2000 | | 2030 | | | 2000 | | 2030 | | | 2000 | | 2030 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | 1975 | Low | High | Low | High | 1975 | Low | High | Low | High | 1975 | Low | High | Low | High |
| Factors affecting useful energy consumption (i) (Group 3.3b) | | | | | | | | | | | | | | | |
| | *Region I* | | | | | *Region II* | | | | | *Region III* | | | | |
| *COOKDW* | 1,000 | 1,000 | | 1,000 | | 1,000 | 1,000 | | 1,000 | | 1,100 | 1,100 | | 1,100 | |
| *DWHW* | 1 | 1 | | 1 | | 0.6 | 0.75 | 0.8 | 0.9 | 1 | 0.7 | 0.9 | 1 | 1 | |
| *HWCAP* | 1,500 | 1,500 | | 1,500 | | 700 | 860 | | 1,000 | | 700 | 900 | 1,060 | 1,100 | 1,400 |
| *DWAC* | 0.39 | 0.46 | 0.51 | 0.5 | 0.6 | 0 | 0.05 | 0.1 | 0.15 | 0.2 | 0 | 0.1 | 0.14 | 0.2 | 0.3 |
| *ACDW* | 4,472 | 5,360 | | 5,800 | | 2,000 | 2,000 | | 2,000 | | 3,000 | 3,000 | | 3,000 | |
| *ELAPDW* | 3,850 | 5,300 | 6,210 | 6,250 | 8,000 | 880 | 2,100 | 2,900 | 3,000 | 5,000 | 1,950 | 3,270 | 3,680 | 4,500 | 6,000 |
| *PREDW* (1) | 0.48 | 0.56 | | 0.6 | | 0.05 | 0.06 | | 0.12 | | 0.1 | 0.2 | 0.26 | 0.3 | 0.4 |
| *PREDW* (2) | 0.32 | 0.37 | | 0.4 | | 0.35 | 0.42 | | 0.8 | | 0.2 | 0.36 | 0.38 | 0.5 | 0.55 |
| *PREDW* (3) | 0.2 | 0.07 | | 0 | | 0.6 | 0.52 | | 0.08 | | 0.7 | 0.44 | | 0.2 | 0.05 |
| *AREAH* | 0.8 | 0.8 | | 0.8 | | 1 | 1 | | 1 | | 0.7 | 0.7 | | 0.7 | |
| *ELARO* | 120 | 126 | 131 | 130 | 150 | 40 | 50 | 60 | 60 | 80 | 40 | 50 | 60 | 60 | 80 |
| *AREAAC* | 0.55 | 0.65 | 0.69 | 0.7 | 0.8 | 0 | 0.07 | 0.15 | 0.2 | 0.3 | 0.05 | 0.1 | 0.15 | 0.15 | 0.2 |
| *ACAREA* | 70 | 70 | | 70 | | 70 | 70 | | 70 | | 70 | 70 | | 70 | |
| *EFFAC* | 2 | 2 | | 2 | | 2 | 2 | | 2 | | 2 | 2 | | 2 | |
| | *Region IV* | | | | | *Region V* | | | | | *Region VI* | | | | |
| *COOKDW* | 1,600 | 1,700 | | 1,800 | | 1,000 | 1,050 | | 1,200 | | 1,600 | 1,700 | | 1,800 | |
| *DWHW* | 0.2 | 0.3 | | 0.35 | | 0.1 | 0.12 | 0.13 | 0.14 | 0.16 | 0.6 | 0.9 | 0.95 | 1 | |
| *HWCAP* | 400 | 600 | 650 | 750 | 1,000 | 40 | 60 | 70 | 100 | 140 | 60 | 175 | 200 | 300 | 400 |
| *DWAC* | 0 | 0.04 | 0.05 | 0.12 | 0.2 | 0 | 0.002 | 0.004 | 0.006 | 0.012 | 0.01 | 0.06 | 0.1 | 0.2 | 0.3 |
| *ACDW* | 1,500 | 2,000 | 2,500 | 2,600 | 3,500 | 1,500 | 2,000 | | 2,600 | | 2,000 | 2,600 | 3,000 | 3,000 | 4,000 |
| *ELAPDW* | 700 | 1,200 | 1,700 | 2,150 | 3,400 | 50 | 115 | 150 | 255 | 485 | 200 | 705 | 942 | 1,209 | 3,300 |
| *PREDW* (1) | 0.08 | 0.08 | | 0.08 | | na | | | | | 0.01 | 0.014 | 0.018 | 0.02 | 0.03 |
| *PREDW* (2) | 0.16 | 0.16 | | 0.16 | | na | | | | | 0.05 | 0.09 | 0.1 | 0.15 | 0.2 |
| *PREDW* (3) | 0.56 | 0.56 | | 0.56 | | 0.35 | 0.4 | 0.45 | 0.55 | 0.65 | 0.4 | 0.6 | 0.75 | 0.82 | 0.77 |
| *AREAH* | 0.8 | 0.85 | 0.87 | 0.95 | 1 | 0.35 | 0.45 | 0.6 | 0.65 | 0.95 | 0.7 | 0.9 | 0.95 | 1 | |
| *ELARO* | 25 | 35 | 40 | 40 | 50 | 15 | 20 | 21 | 25 | 30 | 15 | 30 | 35 | 40 | 50 |
| *AREAAC* | 0.05 | 0.12 | 0.15 | 0.35 | 0.4 | 0 | 0.005 | 0.01 | 0.02 | 0.05 | 0.04 | 0.15 | 0.2 | 0.3 | 0.5 |
| *ACAREA* | 70 | 70 | | 70 | | 70 | 70 | | 70 | | 70 | 70 | | 70 | |
| *EFFAC* | 2 | 2 | | 2 | | 2 | 2 | | 2 | | 2 | 2 | | 2 | |

TABLE 9.3.3 Detailed scenario assumptions – household/service sector *(continued)*.

| | | 2000 | | 2030 | | | 2000 | | 2030 | | | 2000 | | 2030 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | 1975 | Low | High | Low | High | 1975 | Low | High | Low | High | 1975 | Low | High | Low | High |
| Factors affecting useful energy consumption (ii) (Group 3.3c) | | | | | | | | | | | | | | | |
| | *Region I* | | | | | *Region II* | | | | | *Region III* | | | | |
| *DEMDW* | na | 0.02 | | 0.02 | | na | 0.045 | | 0.045 | | na | 0.03 | | 0.03 | |
| *NEWDW* (1) | na | 0.6 | | 0.6 | | na | 0.2 | 0.25 | 0.2 | 0.3 | na | 0.35 | | 0.35 | |
| *NEWDW* (2) | na | 0.4 | | 0.4 | | na | 0.6 | 0.63 | 0.6 | 0.65 | na | 0.5 | | 0.5 | |
| *NEWDW* (3) | na | a | | a | | na | 0.2 | 0.12 | 0.2 | 0.05 | na | 0.15 | | 0.15 | |
| *DWS* (1) | na | 148 | | 150 | | na | 80 | | 100 | | na | 98 | | 110 | |
| *DWS* (2) | na | 88 | | 90 | | na | 62 | | 80 | | na | 74 | | 80 | |
| *DWS* (3) | na | a | | a | | na | 67 | | 85 | | na | 85 | | 95 | |
| *K* (1) | na | 1.9 | | 1.5 | | na | 1.8 | | 1.3 | | na | 1.9 | | 1.5 | |
| *K* (2) | na | 1.7 | | 1.2 | | na | 1.7 | | 1.2 | | na | 1.7 | | 1.2 | |
| *K* (3) | na | a | | a | | na | 0.8 | | 0.7 | | na | 0.7 | | 0.6 | |
| *ISO* (1) | 0 | 0.22 | | 0.3 | | 0 | 0.12 | | 0.2 | | 0 | 0.22 | | 0.3 | |
| *ISO* (2) | 0 | 0.15 | | 0.2 | | 0 | 0.12 | | 0.2 | | 0 | 0.15 | | 0.2 | |
| *ISO* (3) | 0 | 0 | | 0 | | 0 | 0.05 | | 0.1 | | 0 | 0.15 | | 0.2 | |
| *AREAL* | na | 44 | 46.1 | 45 | 48 | na | 37 | 38 | 45 | 50 | na | 30 | 31 | 32 | 35 |
| *DEMAR* | na | 0.03 | | 0.03 | | na | 0.05 | | 0.05 | | na | 0.03 | | 0.03 | |
| *HAREAN* | na | 250 | | 250 | | na | 176 | | 160 | | na | 120 | | 120 | |
| *ELARN* | na | 140 | 150 | 140 | 150 | na | 70 | 80 | 80 | 100 | na | 90 | 94 | 100 | 110 |
| *ISOSV* | 0 | 0.15 | | 0.2 | | 0 | 0.12 | | 0.2 | | 0 | 0.15 | | 0.2 | |
| | *Region IV* | | | | | *Region V* | | | | | *Region VI* | | | | |
| *DEMDW* | na | 0.01 | 0.015 | 0.015 | 0.025 | na | 0.007 | 0.01 | 0.012 | 0.02 | na | 0.015 | 0.02 | 0.025 | 0.03 |
| *NEWDW* (1) | na | 0.16 | | 0.2 | | na | a | | a | | na | 0.025 | 0.03 | 0.035 | 0.05 |
| *NEWDW* (2) | na | 0.28 | 0.36 | 0.4 | 0.52 | na | a | | a | | na | 0.15 | 0.2 | 0.25 | 0.4 |
| *NEWDW* (3) | na | 0.36 | 0.32 | 0.28 | | na | 0.5 | 0.6 | 0.8 | 1 | na | 0.65 | 0.75 | 0.715 | 0.55 |
| *DWS* (1) | na | 120 | | 150 | | na | a | | a | | na | 100 | | 120 | |
| *DWS* (2) | na | 80 | | 90 | | na | a | | a | | na | 70 | | 90 | |
| *DWS* (3) | na | 40 | | 40 | | na | 26 | | 35 | | na | 35 | | 40 | |
| *K* (1) | na | 2.5 | | 2.5 | | na | a | | a | | na | 2.75 | | 2.5 | |
| *K* (2) | na | 2 | | 2 | | na | a | | a | | na | 2.25 | | 2 | |
| *K* (3) | na | 2 | | 2 | | na | 3 | | 3 | | na | 3 | | 3 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *ISO* (1) | 0 | 0.1 | 0.15 | a | | | 0 | 0 | 0 |
| *ISO* (2) | 0 | 0.1 | 0.15 | a | | | 0 | 0 | 0 |
| *ISO* (3) | 0 | 0.1 | 0.15 | 0 | 0 | 0 | 0 | 0 | 0 |
| *AREAL* | na | 20 | 30 | na | 12 13 | 15 18 | na | 20 22 | 30 35 |
| *DEMAR* | na | 0.015 0.02 | 0.02 0.03 | na | 0.007 0.01 | 0.012 0.02 | na | 0.02 0.025 | 0.025 0.03 |
| *HAREAN* | na | 75 | 100 | na | 16 | 20 | na | 35 | 45 |
| *ELARN* | na | 60 70 | 85 100 | na | 35 40 | 45 60 | na | 60 70 | 85 100 |
| *ISOSV* | 0 | 0.02 | 0.02 | 0 | 0 | 0 | 0 | 0 | 0 |

Penetration of alternative energy sources (Group 3.3d)

| | *Region I* | | | *Region II* | | | *Region III* | | |
|---|---|---|---|---|---|---|---|---|---|
| *ELP.H.SH* | 0.12 | 0.21 | 0.25 | 0 | 0.03 | 0.05 | 0.04 | 0.08 | 0.1 |
| *ELP.H.HW* | 0.3 | 0.42 | 0.5 | 0.07 | 0.12 | 0.15 | 0.24 | 0.32 | 0.4 |
| *ELP.H.CK* | 0.47 | 0.6 | 0.7 | 0.15 | 0.22 0.27 | 0.3 0.4 | 0.36 | 0.43 | 0.5 |
| *ELP.S.TH* | 0.05 | 0.17 | 0.25 | 0 | 0.05 | 0.1 | 0.04 | 0.08 | 0.1 |
| *(HPHS)* | (0) | (0.33) | (0.5) | (0) | (0.1) | (0.4) | (0) | (0.33) | (0.5) |
| *EFFHPR* | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| *DHPH* | 0 | 0 | 0 | 0.467 | 0.65 | 0.8 | 0 | 0.12 | 0.25 |
| *SPSH* | 0 | 0.5 | 0.5 | 0 | 0.3 | 0.3 | 0 | 0.5 | 0.5 |
| *FDSHS* | 0.7 | 0.7 | 0.7 | 0.4 | 0.4 | 0.4 | 0.5 | 0.5 | 0.5 |
| *SPHW* | 0 | 0.18 | 0.4 | 0 | 0.08 | 0.2 | 0 | 0.18 | 0.4 |
| *FDHWS* | 0.7 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 |
| *PLB* | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| *SPSV* | 0 | 0.5 | 0.5 | 0 | 0.3 | 0.3 | 0 | 0.5 | 0.5 |
| *FDHS* | 0.7 | 0.7 | 0.7 | 0.4 | 0.4 | 0.4 | 0.55 | 0.55 | 0.55 |
| *CHGNCF* | b | | | 1 | 1 | 1 | b | | |
| | *Region IV* | | | *Region V* | | | *Region VI* | | |
| *ELP.H.SH* | 0.01 | 0.04 | 0.08 | 0.01 | 0.03 | 0.08 | 0.01 | 0.03 | 0.05 |
| *ELP.H.HW* | 0.01 | 0.04 | 0.08 | 0.01 | 0.015 | 0.03 | 0.01 | 0.03 | 0.05 |
| *ELP.H.CK* | 0.005 | 0.03 | 0.1 | 0 | | | 0 | 0.01 | 0.05 |
| *ELP.S.TH* | 0.01 | 0.025 | 0.06 | 0.3 | 0.25 | 0.15 | 0.01 | 0.03 | 0.05 |
| *(HPHS)* | (0) | (0.03) | (0.12) | (0) | (0) | (0) | (0) | (0.02) | (0.12) |
| *EFFHPR* | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| *DHPH* | 0 | 0.03 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 |
| *SPSH* | 0 | 0.3 | 0.5 | | | | 0 | 0.03 | 0.2 |

TABLE 9.3.3 Detailed scenario assumptions – household/service sector *(continued)*.

| Variable | 1975 | 2000 | 2030 | 1975 | 2000 | 2030 | 1975 | 2000 | 2030 |
|---|---|---|---|---|---|---|---|---|---|
| *FDSHS* | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| *SPHW* | 0 | 0.2 | 0.3 | 0 | 0.1 | 0.3 | 0 | 0.02 | 0.15 |
| *FDHWS* | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| *PLB* | 0.3 | 0.3 | 0.3 | 0.7 | 0.6 | 0.5 | 0.7 | 0.6 | 0.5 |
| *SPSV* | 0 | 0.3 | 0.5 | 0 | 0.2 | 0.5 | 0 | 0.03 | 0.2 |
| *FDHS* | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| *CHGNCF* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Fossil fuel efficiencies (relative to electricity) (Group 3.3e) | | | | | | | | | |
| | *Region I* | | | *Region II* | | | *Region III* | | |
| *EFF.H.SH* | 0.63 | 0.73 | 0.8 | 0.59 | 0.63 | 0.65 | 0.63 | 0.665 | 0.7 |
| *EFF.H.HW* | 0.57 | 0.65 | 0.7 | 0.49 | 0.53 | 0.55 | 0.57 | 0.585 | 0.6 |
| *EFF.H.CK* | 0.41 | 0.46 | 0.5 | 0.4 | 0.45 | 0.5 | 0.51 | 0.529 | 0.55 |
| *EFF.S.TH* | 0.7 | 0.76 | 0.8 | 0.59 | 0.63 | 0.65 | 0.7 | 0.725 | 0.75 |
| *EFFNCF* | a | | | 0.3 | | | a | | |
| | *Region IV* | | | *Region V* | | | *Region VI* | | |
| *EFF.H.SH* | 0.6 | 0.63 | 0.7 | 0.5 | 0.53 | 0.6 | 0.6 | 0.63 | 0.7 |
| *EFF.H.HW* | 0.55 | 0.58 | 0.65 | 0.5 | 0.53 | 0.6 | 0.55 | 0.58 | 0.65 |
| *EFF.H.CK* | 0.5 | 0.51 | 0.55 | 0.5 | 0.51 | 0.55 | 0.5 | 0.51 | 0.55 |
| *EFF.S.TH* | 0.65 | 0.68 | 0.75 | 0.55 | 0.58 | 0.65 | 0.6 | 0.63 | 0.7 |
| *EFFNCF* | 0.075 | 0.09 | 0.15 | 0.075 | 0.085 | 0.12 | 0.075 | 0.085 | 0.12 |

na: Not applicable.
a: Category not included for this region.
b: Noncommercial fuels not considered in Regions I and III.
NOTE: Values in parentheses are to be interpreted as fractions of the preceding category.

the changes in the values of the various parameters in 2000 and 2030 in relation to those in 1975 are detailed in Table 9.3.3 for both the High and the Low scenarios. Some general considerations underlying these assumptions and largely applicable to all the regions are:

(1) A continued trend towards a relatively more comfortable living (e.g., larger houses, more central heating, more air-conditioning, more hot water, additional electrical appliances in households, etc.) and provision of better amenities in the service sector (e.g., through increased supply of space/water heating, air-conditioning, lighting, and electrical equipment) with increasing levels of GDP per capita.
(2) Increasing shares of electricity with time (and affluence) in the provision of thermal energy requirements (cooking, space/water heating) of households and services, in line with past trends.
(3) Increasing emphasis on improved insulation of buildings, both new and old, in regions where space heating is an important energy-consuming activity.
(4) Gradual introduction of soft solar devices for space and water heating in both households and service sector buildings leading to a considerable buildup by 2030.
(5) Some improvement in the fossil fuel efficiencies of various thermal devices and, in addition, gradual introduction of heat pumps in places where electricity is to be used for supplying thermal energy.
(6) Introduction or increased use of district heat in regions where settlement patterns and energy requirements favor district heating systems.
(7) Saturation of energy requirements of certain activities, e.g., of cooking energy per dwelling, or of useful thermal energy per $m^2$ of floor area under given climatic conditions.

Although regional characteristics, such as climatic conditions, people's cooking and living habits, construction styles of buildings, etc., have to be taken into account in projecting the likely evolution of various parameters, considerable insight, at least in respect of regions at lower levels of GDP per capita, may be obtained by comparing the base year data (or estimated base year values of various parameters) of different regions at various stages of development. Our projections of scenario parameters draw heavily upon such interregional comparisons.

Noncommercial fuels play an important role in meeting the household energy requirements of the developing regions, particularly of Regions IV and V. Among the developed regions, only Region II has a significant contribution of noncommercial fuels. Although the use of such fuels, particularly that of firewood obtained by indiscriminate cutting of forests, has recently been increasing in the developing regions, we believe that measures will soon be adopted to check this deforestation problem. Accordingly, it has been assumed that the use of noncommercial fuels in the various regions, including Region II, will not be significantly different in 2000 and 2030 from 1975. However, the efficiency in using such fuels is assumed to increase in the developing regions by as much as a factor of 2, due to the introduction of better stoves and other devices in rural areas.

## 5.3 Projected Final Energy Demand

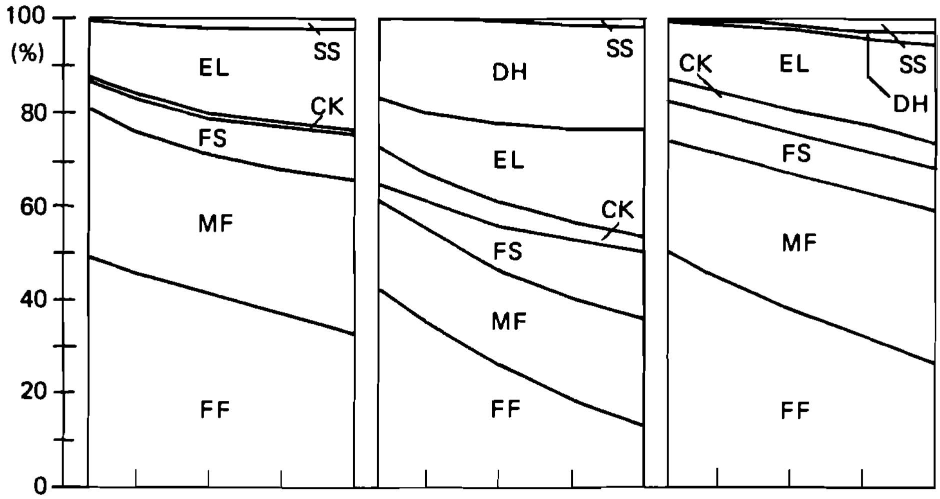
This section is devoted to the salient features of the final energy demand projected for the years 2000 and 2030 in the various world regions, resulting from the detailed scenario assumptions spelled out in Tables 9.1–9.3 and briefly reviewed in Section 5.2.

The evolution of final energy demand in Regions I through VI in the High and the Low scenarios is shown in the projections in Table 10, also incorporating the share of electricity in final energy demand. It is worth noting that the demand for final energy rises much more rapidly in the developing regions than in the developed regions. In the High scenario, 1975–2030, the demand is projected to increase by factors of 10.6 to 14.9 for the developing regions IV, V, and VI, but by factors of only 2.0 to 3.2 for the developed regions I, II, and III. The corresponding increases in the Low scenario are by factors of 6.6 to 7.9 and 1.4 to 2.3, respectively. Among the developing regions, the highest increase in final energy consumption in both the scenarios is projected to occur in Region VI, which had also been assigned higher economic growth (relative to the 1975 level) than Regions IV and V (see Table 3). Similarly, among the developed regions, Region II – which was assigned the highest relative increases in economic development in the basic scenario definitions of Table 3 – is the region projected to have the largest increases in final energy consumption as shown in Table 10.

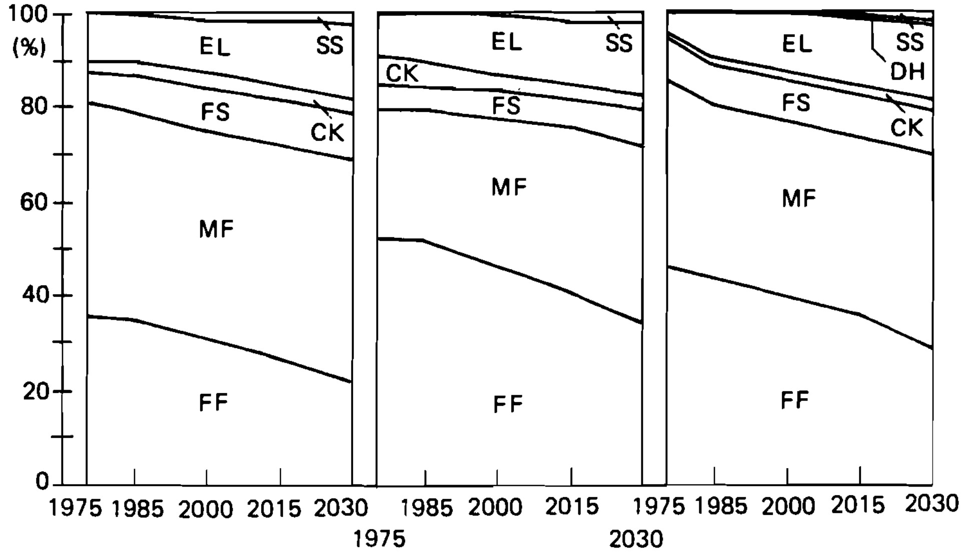
TABLE 10 Final energy in the two scenarios (TWyr/yr).

| | | Projections | | | |
|---|---|---|---|---|---|
| | | High scenario | | Low scenario | |
| Region | 1975 | 2000 | 2030 | 2000 | 2030 |
| I (NA) | 1.87 | 2.63 | 3.67 | 2.26 | 2.64 |
| (% elec.) | (12) | (18) | (20) | (18) | (21) |
| II (SU/EE) | 1.28 | 2.39 | 4.11 | 2.17 | 2.95 |
| (% elec.) | (10) | (17) | (23) | (16) | (20) |
| III (WE/JANZ) | 1.59 | 3.04 | 4.38 | 2.39 | 2.99 |
| (% elec.) | (13) | (17) | (21) | (17) | (21) |
| IV (LA) | 0.25 | 1.00 | 2.64 | 0.73 | 1.66 |
| (% elec.) | (10) | (12) | (15) | (12) | (16) |
| V (Af/SEA) | 0.25 | 1.06 | 3.17 | 0.80 | 1.88 |
| (% elec.) | (9) | (13) | (16) | (12) | (15) |
| VI (ME/NAf) | 0.11 | 0.58 | 1.64 | 0.43 | 0.87 |
| (% elec.) | (4) | (12) | (17) | (12) | (15) |
| I + III | 3.46 | 5.66 | 8.04 | 4.65 | 5.62 |
| (% elec.) | (12) | (17) | (21) | (17) | (21) |
| IV + V + VI | 0.61 | 2.65 | 7.45 | 1.97 | 4.40 |
| (% elec.) | (8) | (12) | (16) | (12) | (15) |
| Total | 5.35 | 10.69 | 19.61 | 8.79 | 12.98 |
| (% elec.) | (11) | (16) | (19) | (16) | (19) |

The share of electricity in final energy is projected to grow in all the world regions in both scenarios, reaching by 2030 20–23 percent in the developed regions (10–13 percent in 1975) and 15–17 percent in the developing regions (4–10 percent in1975). The evolutions over time of the fractional shares of electricity, district heat, soft solar, substitutable fossil fuels, etc., in the final energy demand of different regions, are shown in Figure 6 for the High scenario. The distributions for the Low scenario are very similar



Region 1 Region II Region III



Region IV Region V Region VI

FIGURE 6 Shares of energy forms in final energy demand, 1975–2030 (High scenario). FF = substitutable fossil fuels; CK = specific uses of coal (ess. coke); MF = motorfuel; EL = electricity; SS = soft solar; FS = feedstocks; DH = district heat.

to those in the High scenario and have been omitted. It may be mentioned here that the allocation of substitutable fossil fuels to solids, liquids, and gases is made subsequently to the MEDEE-2 analysis, in the light of expected changes in the fuel prices. These allocations are discussed in Energy Systems Program Group (1981). Further, in the case of developing regions, a significant fraction of the substitutable fossil fuel demand may be met by charcoal and biogas. Estimates for this have been made by Khan (1981).

Although the relative increases in final energy consumption appear large, particularly in the developing regions, they are not as dramatic if seen on a per capita basis (Table 11).

TABLE 11 Per capita final (commercial) energy consumption, two scenarios 1975 to 2030 (kW/cap)*.

| | | High scenario | | Low scenario | |
|---|---|---|---|---|---|
| Region | 1975 | 2000 | 2030 | 2000 | 2030 |
| I (NA) | 7.89 | 9.25 | 11.63 | 7.95 | 8.37 |
| II (SU/EE) | 3.52 | 5.47 | 8.57 | 4.98 | 6.15 |
| III (WE/JANZ) | 2.84 | 4.46 | 5.70 | 3.52 | 3.90 |
| IV (LA) | 0.80 | 1.75 | 3.31 | 1.28 | 2.08 |
| V (Af/SEA) | 0.18 | 0.42 | 0.89 | 0.32 | 0.53 |
| VI (ME/NAf) | 0.80 | 2.34 | 4.64 | 1.76 | 2.46 |
| I + III | 4.34 | 5.87 | 7.43 | 4.82 | 5.20 |
| IV + V + VI | 0.33 | 0.79 | 1.59 | 0.59 | 0.94 |
| I through VI | 1.76 | 2.25 | 3.13 | 1.85 | 2.07 |

NOTE: The figures are average rates of final energy use, averaged over the population and the year.
*For electricity share: see Table 10.

The per capita consumption of final energy in the developing world regions is projected to increase, by 2030, only by a factor of 2.6–3.1 in the Low scenario and of 4.2–5.8 in the High scenario. Accordingly, in 2030, Region V, the poorest among the developing regions, would have a per capita final energy consumption of only 0.5–0.9 kWyr/yr, whereas for the other two developing regions relatively more comfortable levels of 2.4–4.6 kWyr/yr are to be expected. The projected ranges of per capita final energy consumption for the developed regions, in 2030, in the High and Low scenarios, are 5.7–11.6 kWyr/yr and 3.9–8.4 kWyr/yr, respectively, as compared to 2.8–7.9 kWyr/yr in 1975. Thus two out of the three developing market economy regions, i.e., Regions IV and VI, are expected by 2030 to reach levels of per capita final energy consumption comparable to those currently found in some developed regions.

### *5.3.1 Shares of Sectors in Final Energy Demand*

The distribution of final energy demand across three broad sectors: transport, industry (agriculture, construction, mining, and manufacturing), and buildings (household and services) is shown in Table 12 for the year 2030 for each world region, together with the corresponding distribution in 1975. Regional differences in sectoral energy use are apparent. These differences seem to persist in spite of the fact that economic and demographic structures in some of the regions have been assumed to undergo considerable changes over the next 50 years.

Table 12 illustrates that the share of final energy used in buildings is, throughout, much higher in the developed regions than in the developing regions, as one would expect. In addition to low space heating requirements in developing regions, this is also due to the considerable dependence of these regions on noncommercial fuels for domestic

TABLE 12 Shares of sectors in final energy demand (% of final energy).

| Region | Transport | Industry* | Buildings** |
|---|---|---|---|
| *1975* | | | |
| I (NA) | 29 | 40 | *31* |
| II (SU/EE) | 18 | 59 | *23* |
| III (WE/JANZ) | 20 | 51 | *29* |
| IV (LA) | *41* | 47 | 12 |
| V (Af/SEA) | *30* | 59 | 11 |
| VI (ME/NAf) | *39* | 47 | 14 |
| *2030 – High scenario* | | | |
| I (NA) | 28 | 52 | *20* |
| II (SU/EE) | 19 | 64 | *17* |
| III (WE/JANZ) | 25 | 52 | *23* |
| IV (LA) | *44* | 46 | 10 |
| V (Af/SEA) | *29* | 62 | 9 |
| VI (ME/NAf) | *37* | 52 | 11 |
| *2030 – Low scenario* | | | |
| I (NA) | 26 | 50 | *24* |
| II (SU/EE) | 19 | 63 | *18* |
| III (WE/JANZ) | 23 | 49 | *28* |
| IV (LA) | *44* | 43 | 13 |
| V (Af/SEA) | *32* | 55 | 13 |
| VI (ME/NAf) | *36* | 50 | 14 |

*Industry includes agriculture, manufacturing, mining, and construction.
**Buildings in the household and service sectors.
NOTE: Italic figures highlight the most visible of regional differences.

use. Also, building energy use is low in these projections due to saturation effects, which can be seen in almost all world regions.

Transportation activities in the developing regions make up a relatively high share of final energy in 1975 and the trend, in general, shows a slight increase in both scenarios. This is due to a considerable increase in freight transportation, projected to grow with industrial output, as well as to an expected increase in personal travel and a reduction of average load factors. Among the developed regions the relative shares of transportation and industrial activities are markedly different in Regions I plus III (essentially OECD countries) and Region II, mirroring the differing emphasis on industrial activity and personal transportation in the two types of economies.

### *I Energy Demand of Industries*

Industrial energy use is a major portion of the total consumption in every world region today; the scenario assumptions do not lead to major departures from this. Energy as a factor of production, as an "input" to productive output, is an indispensable commodity – qualitatively different from the energy used by households or that consumed in transportation activities. Yet, despite its firm footing in virtually all of the world's economies, industrial energy demand trends and possibilities span an impressively wide range. The scenario assumptions of Section 5.3.2 (see also Table 9.3.1) were based on considerations of such trends and appropriate possibilities in the technoeconomic environment of the various world regions.

Manufacturing activities account for a major share of the industrial energy consumption (Table 13). In 1975 the share of manufacturing activities, including coke use in the steel industry and feedstock inputs to petrochemical industries, out of total industrial energy consumption was 90 to 97 percent for Regions I to V in spite of considerable differences in the composition of their economic structure. In Region VI this share was relatively smaller – about 62 percent – due to the exceptionally low level of manufacturing activity and the dominance of oil and gas production activity in the industrial sector of this region. The scenario assumptions of changes in economic structure, composition of manufacturing activities, and technological coefficients result in projections for the years 2000 and 2030 for which the share of manufacturing in the industrial energy consumption varies between 76 and 90 percent in all world regions.

TABLE 13 Final energy projections for industry, including coke and feedstocks (TWyr/yr).

| | | High scenario | | Low scenario | |
|---|---|---|---|---|---|
| Region | 1975 | 2000 | 2030 | 2000 | 2030 |
| I (NA) | 0.76 | 1.31 | 1.91 | 1.08 | 1.31 |
| (% manuf.) | (92) | (91) | (89) | (91) | (90) |
| II (SU/EE) | 0.76 | 1.49 | 2.64 | 1.35 | 1.85 |
| (% manuf.) | (92) | (91) | (90) | (90) | (88) |
| III (WE/JANZ) | 0.81 | 1.55 | 2.27 | 1.18 | 1.46 |
| (% manuf.) | (91) | (89) | (89) | (90) | (89) |
| IV (LA) | 0.12 | 0.48 | 1.23 | 0.33 | 0.72 |
| (% manuf.) | (90) | (91) | (90) | (89) | (87) |
| V (Af/SEA) | 0.15 | 0.67 | 1.97 | 0.47 | 1.02 |
| (% manuf.) | (97) | (88) | (82) | (85) | (76) |
| VI (ME/NAf) | 0.05 | 0.32 | 0.85 | 0.24 | 0.43 |
| (% manuf.) | (62) | (83) | (86) | (85) | (80) |

Table 14 lists the present and projected final energy demand of the manufacturing sector in different world regions and also indicates the shares of electricity and coke plus feedstocks (essentially liquid fuel based, used in petrochemical industries) in this demand. It is seen that the share of electricity in manufacturing energy demand increases in all regions, reaching levels of 20–25 percent in 2030 as against 11–15 percent at present. The share of coke plus feedstocks also increases in all the regions (except in Region VI where petrochemical feedstock production for export purposes is currently an important activity from 13–28 percent in 1975 to 20–33 percent in 2030. Various factors are responsible for these changes. Some of the more important ones are assumed to be the following: (1) a greater reduction in the energy intensity of manufacturing activities with respect to useful thermal energy than with respect to specific uses of electricity (e.g., motive power, electrolysis, lighting); (2) penetration of electricity in the useful thermal energy market of the manufacturing processes; (3) a relatively small reduction in the demand of coke per ton of pig-iron production in the developed regions, and (4) increasing importance of the basic materials industries in the manufacturing sectors of the developing countries.

TABLE 14 Final energy projections for manufacturing, including coke and feedstocks (TWyr/yr).

| Region | 1975 | High scenario 2000 | High scenario 2030 | Low scenario 2000 | Low scenario 2030 |
|---|---|---|---|---|---|
| I (NA) | 0.70 | 1.19 | 1.70 | 0.98 | 1.19 |
| (% elec.) | (13) | (18) | (21) | (18) | (20) |
| (% coke + feedst.) | (18) | (21) | (23) | (21) | (22) |
| II (SU/EE) | 0.70 | 1.35 | 2.37 | 1.22 | 1.62 |
| (% elec.) | (12) | (18) | (24) | (16) | (21) |
| (% coke + feedst.) | (20) | (26) | (31) | (24) | (26) |
| III (WE/JANZ) | 0.73 | 1.39 | 2.01 | 1.05 | 1.30 |
| (% elec.) | (15) | (19) | (24) | (19) | (21) |
| (% coke + feedst.) | (28) | (32) | (33) | (31) | (32) |
| IV (LA) | 0.11 | 0.44 | 1.10 | 0.29 | 0.63 |
| (% elec.) | (14) | (16) | (21) | (17) | (21) |
| (% coke + feedst.) | (22) | (28) | (33) | (27) | (33) |
| V (Af/SEA) | 0.14 | 0.59 | 1.62 | 0.40 | 0.77 |
| (% elec.) | (11) | (15) | (21) | (15) | (20) |
| (% coke + feedst.) | (13) | (16) | (20) | (15) | (18) |
| VI (ME/NAf) | 0.03 | 0.26 | 0.73 | 0.20 | 0.35 |
| (% elec.) | (12) | (20) | (25) | (20) | (25) |
| (% coke + feedst.) | (33) | (22) | (25) | (23) | (26) |

We now look at the changes in energy intensity of the manufacturing industries (excluding the use of coke in steel industry, and the use of liquid fuels for feedstock production) that result from our scenario assumptions of Table 9.3 1. Also we indicate to what extent the shifts, assumed to occur in the great variety of manufacturing activities in the world regions, are responsible for these changes. The requirements of energy for a given mix of manufacturing activities can be reduced in various ways: (1) by incorporating better machinery and processes (which reduces the energy intensity of these activities) (2) by increasing the shares of electricity, district heat, and soft solar energy in meeting the demand for thermal processes (which reduces conversion losses), (3) by making increased use of cogeneration and heat pumps (which reduces the requirements of final energy); and (4) by improving the efficiency of fossil fuel conversion to process heat (which also reduces conversion losses). Tables 15 and 16 summarize some of our previously described assumptions (see Tables 9.2 and 9.3.1) for the year 2030 according to the High scenario, in aggregated and/or more transparent form. The data for 1975 (column 1, Table 15) show considerable differences in the average useful energy intensity of manufacturing activities in the various world regions. These differences are partly due to different mixes of component activities and partly due to differences in processes, technologies, and the extent of automation.

These projections (Table 15) in general indicate a greater potential for reduction of energy intensity in the developed regions than in the developing regions. These reductions -- which are in part due to structural changes in manufacturing -- are especially large in Regions II and I, but not so large in Region III where manufacturing activities have already undergone considerable modernization. The largest structural changes in the manufacturing sector are assumed for the developing regions (see Table 9.2), where both the most energy-intensive basic materials industries and the least energy-intensive

TABLE 15 Projected reduction in average useful energy intensity of manufacturing industries, High scenario.

| Region | Useful energy intensity (kWhr(e)/$VA 1975 | 2030 | % reduction in 2030 relative to 1975 | Of which (%) due to structural change* |
|---|---|---|---|---|
| I (NA) | 8.66 | 6.06 | 30 | 8 |
| II (SU/EE) | 10.86 | 6.12 | 44 | 1 |
| III (WE/JANZ) | 4.20 | 3.21 | 24 | 4 |
| IV (LA) | 5.81 | 4.51 | 22 | 4 |
| V (Af/SEA) | 11.06 | 9.29 | 16 | −3 |
| VI (ME/NAf) | 7.68 | 4.96 | 35 | −8 |

*Structural changes are the result of modernization in the manufacturing activities.

NOTE: Useful energy is expressed as equivalent electricity requirement. Data are for manufacturing industries, excluding coke and petrochemical feedstock use.

TABLE 16 Assumed penetration of electricity, district heat, cogeneration, heat pump and soft solar in their potential industrial heat markets in 2030, High scenario (% of potential industrial heat markets)*.

| Region | Electricity | District heat | Cogeneration | Heat pump | Soft solar Low temp. | Soft solar High temp. |
|---|---|---|---|---|---|---|
| I (NA) | 0.10 | 0 | 0.50 | 0.50 | 0.15 | 0.05 |
| II (SU/EE) | 0.10 | 0.85** | 0 | 0 | 0.10 | 0.03 |
| III (WE/JANZ) | 0.05 | 0.15 | 0.60** | 0.50 | 0.15 | 0.05 |
| IV (LA) | 0.10 | 0.12 | 0.20 | 0.20 | 0.30 | 0.10 |
| V (Af/SEA) | 0.04 | 0.05 | 0.15 | 0.10 | 0.30 | 0.10 |
| VI (ME/NAf) | 0.10 | 0.12 | 0.25 | 0.20 | 0.30 | 0.10 |

*Potential industrial heat markets: electricity, all process heat; district heat, steam and hot water; cogeneration, low temperature steam and hot water; heat pump, steam and hot water demand met by electricity; and soft solar, steam and hot water.

**In Region II district heat and in Region III on-site cogeneration were already supplying 69 percent and 30 percent of their respective potential markets in 1975.

machinery and equipment industries grow relatively faster than the nondurable goods industries; this has a balancing effect on the overall energy intensity of manufacturing.

As mentioned in Section 5.2.3, Part I, the penetration of various more efficient energy forms as well as of cogeneration and heat pumps in the industrial heat market was projected in the light of regional differences in settlement patterns, past practices, current technological trends, geographical conditions, etc. All these technological changes essentially aim at reducing the demand of fossil fuels for industrial process heat. Yet, in spite of our rather optimistic assumptions of Table 16, more than 80 percent of the industrial process heat requirements in all the regions except in Region II would still have to be met by fossil fuels in 2030 in the High scenario (Table 17). Note again that improvements in the average efficiency of fossil fuel use of the order of 20 percent are also assumed to be possible over the next 50 years (see Table 9.3.1, Group 3.1f). Table 17 lists the shares of various energy sources (fossil fuels, electricity, district heat, soft solar) in the heat demand of manufacturing industries resulting from the assumptions of the High scenario.

TABLE 17 Shares of energy sources in the heat market of the manufacturing sector, High scenario (% of total useful thermal energy).

| | 2000 | | | | | | 2030 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Region | FF | (COG) | EL | (HP) | DH | SS | FF | (COG) | EL | (HP) | DH | SS |
| I (NA) | 92 | (5.9) | 7 | (1.2) | 0 | 1 | 87 | (9.0) | 10 | (2.5) | 0 | 3 |
| II (SU/EE) | 39 | (0.0) | 5 | (0.0) | 55 | 1 | 30 | (0.0) | 10 | (0.0) | 59 | 1 |
| III (WE/JANZ) | 92 | (8.1) | 3 | (0.5) | 4 | 1 | 85 | (10.8) | 5 | (1.3) | 8 | 2 |
| IV (LA) | 95 | (0.4) | 3 | (0.1) | 1 | 1 | 80 | (1.6) | 10 | (0.8) | 5 | 5 |
| V (Af/SEA) | 99 | (0.2) | 1 | (0.0) | 0 | 0 | 90 | (0.9) | 4 | (0.2) | 2 | 4 |
| VI (ME/NAf) | 95 | (0.9) | 3 | (0.0) | 1 | 1 | 81 | (1.5) | 10 | (0.8) | 5 | 4 |

NOTE: FF = fossil fuels; COG = with cogeneration of electricity (included in FF); EL = electricity; HP = (electric) heat pumps (included in EL); DH = district heat; SS = soft solar.

In 1975, the fossil fuel share is 100 percent in all regions except Regions II (48 percent district heat); in Region III, cogeneration was estimated to be 5 percent.

The overall effect of these technological developments, better practices, and structural changes is a reduction in the average final energy intensity of manufacturing activities (excluding feedstocks and the use of coke in the steel industry) by about 35 to 55 percent in the regions for the High scenario, as is shown in Table 18. The effects of structural changes are not very large (see Table 15) due to the high sectoral aggregation. A larger reduction in final energy intensity, as compared to that in useful energy intensity, is due to higher final-to-useful energy conversion efficiency, assumed to improve by 20–30 percent.

At present, use of coke in the steel industry amounts to 2–11 percent of the final energy requirements of manufacturing activities in the various world regions. The consumption of coke per ton of pig-iron produced varies considerably from country to country. Estimated regional averages for 1975 are between 500 kg in Region III (WE/JANZ) and 1,000 kg in Region VI (ME/NAf). The scenario assumptions of Table 9.3.1, Group 3.1h, imply reduction in coke consumption of 20–60 percent in the various world regions. The share of coke for the steel industry in the industrial final energy demand of the regions changes only slightly (except for Region II) over a period of 50 years and stays within a range of 2–10 percent in both the High and the Low scenarios. In Region II, this share would fall from 11 percent in 1975 to about 4.5 percent in 2030.

TABLE 18 Average final energy intensity of manufacturing activities, excluding feedstocks and coke.

| | Energy intensity, High scenario (kWhr(e)/$VA) | | | |
|---|---|---|---|---|
| Region | 1975 | 2030 | Relative decrease (%) | Reduction due to structural change (%) |
| I (NA) | 12.3 | 7.0 | 43 | 6 |
| II (SU/EE) | 13.9 | 6.4 | 54 | 1 |
| III (WE/JANZ) | 5.7 | 3.6 | 37 | 4 |
| IV (LA) | 8.6 | 5.5 | 36 | 3 |
| V (Af/SEA) | 19.6 | 12.6 | 36 | −2 |
| VI (ME/NAf) | 12.2 | 6.1 | 50 | −7 |

We consider here the share of agriculture in the industrial energy demand. Agriculture in developing regions, based largely on traditional farming practices, is currently far less energy intensive than that in developed regions. According to the economic projections of the scenarios (see Table 9.2), the agricultural GDP in Regions IV, V, and VI is expected to increase by a factor of 3.7 to 4.5 over the next 50 years; the expected increase would be 2.2 to 2.5 times in Regions I, II, and III. The implications of these projections in energy terms can be seen in the parameters of Table 19.

TABLE 19 Agricultural patterns in different world regions in 1975.

| Region | Arable land per capita (ha/cap) | Irrigation (% of arable land) | Mechanical appliances (per 1,000 ha) | Fertilizer use (kg/ha) |
|---|---|---|---|---|
| I (NA) | 1.07 | 7 | 22 | 80 |
| II (SU/EE) | 0.77 | 7 | 15 | 96 |
| III (WE/JANZ) | 0.34 | 9 | 45 | 117 |
| IV (LA) | 0.45 | 9 | 7 | 32 |
| V (Af/SEA) | 0.32 | 14 | 1 | 14 |
| VI (ME/NAf) | 0.33 | 25 | 4 | 27 |
| VII (C/CPA) | 0.15 | 61 | 2 | 50 |

NOTE: All data refer to arable land including land under permanent crops. *Mechanical appliances* included here are tractors and harvesters. *Fertilizer use* refers to consumption in terms of $N_2$, $P_2O_5$ and $K_2O$.
SOURCES: FAO 1977, UN 1977b.

Consider arable land in developing regions. There is little potential for expanding arable land area in Regions IV, V, and VI where the present per capita availability of arable land is about 0.34 ha compared to 0.62 ha in the developed Regions I, II, and III. If no significant new area is brought under cultivation, the per capita availability will decrease over the next 50 years to 0.14 ha in the developing regions and 0.46 ha in the developed regions.

The limits on arable land expansion imply that essential agricultural productivity improvements must come from increases in the use of fertilizers, irrigation, and farm mechanization. But surface water is in short supply and precipitation is not adequate in most areas; increasing use will therefore have to be made of underground water.

Taking these factors into account, the energy intensity of agriculture – including mechanization and irrigation, but not including energy used to produce fertilizers – in Regions IV, V, and VI was assumed to increase by a factor of 10 over the next 50 years (see Table 9.3.1, Group 3.1c). Thus by 2030 the average energy intensity in these regions would be about the same (2.8 kWhr/\$VA*) as the present average value for the developed regions. The final energy used in agriculture would increase for the High and Low scenarios by about 45 and 37 times the 1975 level in the developing regions, and by just 2.4 and 2.0 times in the developed regions. The share of agricultural activities in industrial energy consumption in 2030 is thus found to lie in the range of 3 to 5 percent in all regions

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*\$VA = \$ value added.

except V where it amounts to 10 percent for the High scenario and 15 percent for the Low scenario. (The shares in all the regions in 1975 were in the range of 1 to 4 percent.)

Energy needed for fertilizer production is counted in this analysis in the basic materials manufacturing sector. For Regions IV and V those sectors are projected to increase in output by 2030 to about 10 to 20 times their 1975 levels. These increases should easily encompass the energy demand for chemical fertilizer, which may increase by a factor of 5 to 10 in the same period.

### *II Energy Demand of Transportation*

Transportation activities take an appreciable share of the total final energy (see Table 12). In 1975 this share was about 20 percent in Regions II and III, 30 percent in Regions I and V, and 40 percent in Regions IV and VI; for the world as a whole, the share was about 24 percent. Of course, the ways in which this energy is used (the mix of transport modes – cars, buses, trains, trucks, planes – and the fuels used) vary considerably from country to country. The end result is usually a large share of energy use in transport; and one that has been growing.

The analysis reported here foresees some changes in this picture: relatively slower growth in personal travel in developed regions (except for air travel); moderately increased use of public transportation for urban travel (a consequence of growing urban traffic congestion); and greater economies of gasoline consumption (see Table 9.3.2). These assumed changes are due to relative price increases, changes in public perceptions about energy availability (which may or may not be accompanied quickly by price changes), and government mandates.

The results are strikingly different in different parts of the world, as is shown in Table 20. Region I (NA) evidences the smallest relative increase in transportation energy use, although the high mobility, great distances, and large (but slowly shrinking) cars of the US and Canada, keep the absolute level of energy use high. However, the share of passenger travel in transportation activity declines considerably – from 75 percent in 1975, to 40–50 percent in 2030. In Regions II and III, demand of energy for both passenger travel and freight transportation continues to increase steadily with only minor changes in the relative shares of these two activities in total transportation energy. It may be pointed out here that in Region II (SU/EE), transportation energy use is currently low compared to both NA and WE/JANZ, despite large distances. The main factors for this contrast are the high share of rail in both freight and passenger transportation, and the emphasis on urban mass transit. Although a certain increase in car ownership and attendant increase in energy use for personal transportation is envisaged in SU/EE, the total increase is not so marked because in freight transportation no significant shift towards trucks is expected.

In the developing Regions IV, V, and VI, growth in transport energy demand is significantly higher, owing to greater freight transport accompanying growth in industrial and agricultural output, and to the fact that personal travel is far from the saturation mark. Further, the share of passenger travel in transportation energy demand increases in all developing regions, although the change is not as large in Region IV (LA) as in the other two regions.

Table 20 also shows the share of electricity in transportation energy demand resulting from the scenario assumptions of Table 9.3.2. In Regions I, IV, V, and VI, this share

TABLE 20 Projections of transportation final energy demand (TWyr/yr).

| | | High scenario | | Low scenario | |
|---|---|---|---|---|---|
| Region | 1975 | 2000 | 2030 | 2000 | 2030 |
| I (NA) | 0.54 | 0.65 | 1.01 | 0.56 | 0.68 |
| (% elec.) | (0.1) | (0.6) | (1.1) | (0.7) | (1.5) |
| (% passenger) | (74) | (48) | (39) | (54) | (49) |
| II (SU/EE) | 0.22 | 0.42 | 0.79 | 0.38 | 0.55 |
| (% elec.) | (4.0) | (6.4) | (8.9) | (6.3) | (9.2) |
| (% pass.) | (25) | (30) | (27) | (28) | (28) |
| III (WE/JANZ) | 0.31 | 0.71 | 1.11 | 0.53 | 0.69 |
| (% elec.) | (1.9) | (2.2) | (3.1) | (2.6) | (3.9) |
| (% pass.) | (60) | (59) | (54) | (58) | (56) |
| IV (LA) | 0.11 | 0.41 | 1.15 | 0.30 | 0.73 |
| (% elec.) | (0.2) | (0.4) | (1.4) | (0.4) | (1.5) |
| (% pass.) | (31) | (33) | (35) | (35) | (38) |
| V (Af/SEA) | 0.08 | 0.27 | 0.91 | 0.22 | 0.61 |
| (% elec.) | (0.5) | (0.8) | (1.5) | (0.8) | (1.6) |
| (% pass.) | (40) | (45) | (55) | (47) | (59) |
| VI (ME/NAf) | 0.04 | 0.20 | 0.61 | 0.14 | 0.31 |
| (% elec.) | (0.1) | (0.2) | (0.9) | (0.2) | (1.0) |
| (% pass.) | (20) | (23) | (34) | (26) | (34) |

increases from a very low level of 0.1–0.5 percent in 1975 to a modest level of 1.0–1.5 percent in 2030. The same share in Region III would increase from about 2 percent in 1975 to 3–4 percent in 2030; whereas for Region II, the projected increase over the same period, is from an already high level of 4 percent to a still higher level of 9 percent.

*Passenger travel.* Consider the relative levels of passenger transport activity around the world in 1975. Total passenger travel (intercity plus urban) in North America in 1975 was some 4,100 billion ($10^9$) passenger-kilometers (population 237 million, $10^6$); in Region II it was 1,700 billion (population 363 million); in Region III over 5,000 billion (population 560 million). The total activity for developing Regions IV, V, and VI together was only 3,000 billion passenger-kilometers, for 1,874 million people. But this seems sure to change. Passenger travel in the developed regions is expected to be nearing saturation levels – further increases will probably be relatively modest. (There are limits, of income and time, to how much one can travel.) This effect is especially pronounced in Region I. Regions I and III together show only a 1.2 to 1.6 percent per year growth in total passenger travel according to the MEDEE-2 runs for the two scenarios to 2030. The developing Regions IV, V, and VI together increase their personal travel amount by 3.9 to 4.4 percent per year. The Region II growth rate is projected at 1.9 to 2.4 percent per year.

But the types or modes of travel and relative load factors are also to be considered. Table 21 summarizes, for the High scenario, the results of an array of assumptions for urban and intercity mobility, relative growth of different transport modes, and expected changes in load factors around the world (see Table 9.3.2). It is apparent in Table 21 that passenger travel in NA is assumed to shift away from automobiles and towards airplanes in the scenarios. Still, by 2030 the car would account for 73 percent of total passenger-kilometers, compared to 50 percent or less in other regions. In general, developed regions

TABLE 21 Assumptions on passenger travel (intercity and urban) and its distribution by mode of transportation, High scenario.

| Region | Activity level ($10^3$ km/per/yr) | Modal split (%) | | | |
|---|---|---|---|---|---|
| | | Plane | Car | Train* | Bus |
| *1975* | | | | | |
| I (NA) | 17.4 | 4 | 93 | 1 | 2 |
| II (SU/EE) | 4.8 | 11 | 26 | 51 | 12 |
| III (WE/JANZ) | 9.2 | 3 | 37 | 37 | 23 |
| IV (LA) | 4.1 | 1 | 37 | 5 | 57 |
| V (Af/SEA) | 1.0 | 1 | 25 | 14 | 60 |
| VI (ME/NAf) | 2.2 | 1 | 29 | 5 | 65 |
| *2000* | | | | | |
| I (NA) | 21.7 | 12 | 83 | 2 | 3 |
| II (SU/EE) | 9.1 | 13 | 29 | 45 | 13 |
| III (WE/JANZ) | 13.5 | 9 | 44 | 27 | 20 |
| IV (LA) | 7.5 | 3 | 45 | 5 | 47 |
| V (Af/SEA) | 2.0 | 2 | 32 | 11 | 55 |
| VI (ME/NAf) | 6.3 | 2 | 34 | 9 | 55 |
| *2030* | | | | | |
| I (NA) | 25.9 | 20 | 73 | 3 | 4 |
| II (SU/EE) | 13.3 | 15 | 30 | 41 | 14 |
| III (WE/JANZ) | 18.0 | 12 | 50 | 20 | 18 |
| IV (LA) | 13.5 | 4 | 49 | 9 | 38 |
| V (Af/SEA) | 4.6 | 2 | 39 | 10 | 49 |
| VI (ME/NAf) | 15.9 | 4 | 38 | 15 | 43 |

*Train includes urban electric mass transit.

SOURCES: UN (1977c); IRF (1976); Europa (1976); CMEA (1976).

are projected to continue observed tendencies toward relatively more air and (except NA) car travel; developing regions reflect expected shifts towards cars (noticeably) and trains (less noticeably), and away from the current large fraction of bus travel (roughly 60 percent in developing regions and less than 20 percent in developed regions).

*Automobiles.* Cars consume prodigious amounts of energy. More precisely, they consume prodigious amounts of petroleum – a particularly important distinction.

In North America, total automobile travel (intercity and urban) is assumed to grow from 3,800 billion passenger-kilometers in 1975 (that is equivalent to four automobile trips coast to coast across the US per person per year) to about 6,000 billion by 2030. This average growth rate of just 0.8 percent per year indicates a leveling-off in the so-far continuously increasing automobile use in this region. The Region III growth in total car travel, by contrast, is assumed to be 1.6–2.4 percent per year; while in Region II it is assumed to be 2.1–2.7 percent per year. In the developing Regions IV, V, and VI the corresponding rates are between 4 and 6 percent per year – even though the assumptions restrict urban car travel because of city traffic congestion to 35–50 percent of all urban passenger travel.

Assumptions for car ownership and usage vary widely among regions, as recorded in Table 9.3.2, Group 3.2e. Car ownership, and the distance traveled per car are thought to be nearing limits in North America. Region IV, Latin America, is assumed to approach the present statistics of Region III by 2030, whereas the figure for Region V in 2030 may be comparable to Region IV today. In Regions IV, V, and VI the relatively high growth of car ownership in the scenarios results from assumed higher growth in GDP per capita and anticipated increases in urbanization.

Region II (SU/EE), has now low car ownership and high distance traveled per car – figures more typical of developing regions. The scenarios for this region maintain that automobile ownership will continue to be low, reaching only half of the present WE/JANZ level by 2030. This reflects the explicit desire in this region to develop public transport facilities, to minimize the need for private automobile use, and thus to minimize liquid fuel requirements.

Energy use in vehicles can be reduced significantly by increasing load factors – average number of passengers per trip, or passenger-kilometers divided by vehicle-kilometers – and by improving the vehicle's energy-using efficiency (see Table 9.3.2, Groups 3.2f and 3.2g). Load factors for automobiles are assumed to be constant in the scenario cases in the developed regions, but are reduced somewhat in the developing regions as cars become more common and family sizes decrease. However, the largest factor in reducing potential per-kilometer energy use in cars is efficiency improvement. The major share of this potential is found, not surprisingly, in North America.

Electric cars offer a potential for reduction of motor fuel use in automobiles. Electric cars are assumed to be three times as efficient as internal combustion engine automobiles, but nevertheless would consume about the same total primary energy as conventional cars if the electricity came from central station sources. It is assumed here (see Table 9.3.2, Group 3.2e) that by 2030 about 20 percent of urban car travel in the developed regions I, II, and III and perhaps 5 percent of urban car travel in the developing regions IV and VI might be accounted for by electric cars.

As a result of these and other assumptions, automobile energy use declines sharply in Region I, and shows a modest decline (as a share of total transportation energy use) in Region II and III. Regions IV, V, and VI contrast sharply with these results, with marked increases in total automobile energy use, largely because of the current low level of use.

Table 22 shows these projections for automobile energy use in the scenarios. The quantities are large, as can be seen. The gasoline consumption in cars in 2030 in Regions 1 through VI would amount to about 0.9 to 1.1 TWyr/yr of oil. One must ask the extent to which alternative transport modes could replace the car, and with what energy consequences.

*Mass transit.* In the projections over 50 years, North Americans travel relatively less by car for intercity trips, than currently. One reason is an assumed modest shift away from cars and toward mass transit for intercity travel. In other regions, the shift assumed is actually toward cars for intercity travel, but trains continue to play a very significant role in Regions II, III, V, and VI – by 2030, 35 to 40 percent in Region II, 20 to 35 percent in Region III, 16 percent in Region V, and 20 percent in Region VI, from 53 percent, 42 percent, 26 percent, and 10 percent in 1975. In Regions I and IV, train intercity travel is assumed to remain low – 1 and 6 percent, respectively, of all intercity travel in 1975 to about 2 and 3 percent, respectively, in 2030 (see Table 21).

TABLE 22 Energy use by automobiles in six world regions (GWyr/yr).

| | | High scenario | | Low scenario | |
|---|---|---|---|---|---|
| Region | 1975 | 2000 | 2030 | 2000 | 2030 |
| I (NA) | | | | | |
| Energy used by cars | 364 | 205 | 194 | 203 | 201 |
| As % of total transportation energy | (67) | (32) | (19) | (36) | (29) |
| II (SU/EE) | | | | | |
| Energy used by cars | 26 | 45 | 63 | 42 | 50 |
| As % of total transportation energy | (11) | (11) | (8) | (11) | (9) |
| III (WE/JANZ) | | | | | |
| Energy used by cars | 111 | 214 | 249 | 168 | 179 |
| As % of total transportation energy | (35) | (30) | (22) | (32) | (26) |
| IV (LA) | | | | | |
| Energy used by cars | 20 | 82 | 238 | 67 | 179 |
| As % of total transportation energy | (19) | (20) | (21) | (22) | (25) |
| V (Af/SEA) | | | | | |
| Energy used by cars | 17 | 67 | 277 | 60 | 216 |
| As % of total transportation energy | (22) | (25) | (30) | (27) | (36) |
| VI (ME/NAf) | | | | | |
| Energy used by cars | 6 | 27 | 108 | 22 | 67 |
| As % of total transportation energy | (13) | (13) | (18) | (16) | (21) |

Travelers take to the air in greatly increasing numbers in these scenario projections for the developed market economies, both High and Low cases. The rate of growth is also high for developing regions, but from a much smaller starting amount. In Region IV intercity air travel would grow from 2.6 percent in 1975 to 6–8 percent by 2030; in Regions V and VI the increase would be from 1.5 percent in 1975 to 3–7 percent by 2030 in the scenarios. In North America, airplane flights would account for as much as 30 percent of all intercity travel in 2030 (from 7 percent currently), while Region III would increase air travel from 3.5 percent currently to as much as 18 percent of all intercity travel by 2030. In Region II, air travel may account for as much as 27 percent of all intercity movements by 2030, from 20 percent currently.

In most cases load factors for trains, planes, and buses, are assumed to be approximately constant or increase only marginally in Regions I and III. This is not the case in the developing regions – overcrowding on buses and trains is the norm, not the exception. High population growth, coupled with the high mobility preferences accompanying income increases, keep the Regions IV and V load factors high, although a gradual relaxation of the present overcrowding is assumed to occur in parallel with increasing per capita income and slowing down of population growth. Load factors of 20 and 25 passenger-kilometers per vehicle-kilometer for buses and about 140 for trains are common for Regions I and III. In Regions IV, V, and VI the bus load factors of 40–50 currently, fall to 20–40 by 2030 in the scenarios, while train load factors fall from 500 to 200–400*. The bus and train load factors in Region II are also assumed to fall by a factor of 2 over the next 50 years and become comparable to those in Regions I and III (see Table 9.3.2, Group 3.2f).

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*Of course, varying "vehicle" size among and even within regions increases the difficulties of drawing comparisons.

*Freight transportation.* Freight transport is assumed to grow significantly in all world regions roughly in parallel with the activity levels in the agriculture, mining manufacturing, and energy sectors. It is a big business: some 5 trillion ($10^{12}$) ton-kilometers of freight in 1975 reaches, by 2030, 11 trillion in the Low scenario and 19 trillion in the High scenario for the developed Regions I and III. Energy use increases by a factor of 2.4 to 3.9 over the 50-year period. (See Tables 20 and 23.) Freight transportation activity is much lower in Regions IV, V, and VI. These regions together had only about 2 trillion ton-kilometers of freight movement in 1975; an increase of 6 to 10 times that level is projected by 2030. Gradual shifts toward increasing freight transportation on trains in Regions IV and VI and with trucks in Region V are assumed. No significant change is assumed in the present distribution of freight transportation modes in the developed regions I, II, and III. As a result of these assumptions, together with those concerning passenger travel, the share of freight movement in transportation energy would increase in Regions I and III and decrease, to varying extents, in other regions (see Table 20).

TABLE 23 Projections of freight transportation activity ($10^{12}$ ton-km).

| Region | 1975 | High scenario 2000 | High scenario 2030 | Low scenario 2000 | Low scenario 2030 |
|---|---|---|---|---|---|
| I (NA) | 3.1 | 7.0 | 12.5 | 5.5 | 7.4 |
| II (SU/EE) | 4.6 | 10.0 | 21.8 | 9.2 | 15.2 |
| III (WE/JANZ) | 1.5 | 3.5 | 6.0 | 2.7 | 3.7 |
| IV (LA) | 0.9 | 3.4 | 9.9 | 2.5 | 5.9 |
| V (Af/SEA) | 0.5 | 1.8 | 4.8 | 1.4 | 2.9 |
| VI (ME/NAf) | 0.6 | 2.0 | 5.3 | 1.4 | 2.8 |

### *III Energy Demand of the Household/Service Sector*

Table 24 lists the commercial final energy, demand projections of the household/service sector in various regions. The evolution of energy demand in this sector markedly differs between the regions. According to these projections, the demand would increase by a factor of 7 to 12 in the developing regions IV, V, and VI, by a factor of about 2 in Regions II (SU/EE) and III (WE/JANZ); and by less than 30 percent in Region I (NA) over the next 50 years. The share of services in the final energy demand of the household/service sector as a whole seems to increase in all the regions, with the largest increase occurring in Region VI and the smallest one in Region I. The use of electricity grows quite rapidly in both households and services so that an increasingly larger fraction of the demand of this sector will, in the future, have to be met by electricity in all the world regions. The share of electricity, in 2030, for various world regions, is projected to be in the range of 30–50 percent for the High scenario as against 7–28 percent in 1975. These projections are the net outcome of our assumptions concerning likely changes in the values of a large number of parameters (see Table 9.3.3) that were considered necessary to describe the evolution of energy demand of this sector. In order to put these projections in proper perspective we give here a brief overview of the above-mentioned scenario assumptions in a relatively more aggregated form.

TABLE 24 Projections of final energy demand* in the household/service sector (TWyr/yr).

| | | High scenario | | Low scenario | |
|---|---|---|---|---|---|
| Region | 1975 | 2000 | 2030 | 2000 | 2030 |
| I (NA) | 0.57 | 0.66 | 0.74 | 0.62 | 0.64 |
| (% elec.) | (23) | (39) | (50) | (37) | (46) |
| (% serv.) | (28) | (30) | (33) | (27) | (28) |
| II (SU/EE) | 0.29 | 0.48 | 0.69 | 0.44 | 0.55 |
| (% elec.) | (7) | (21) | (33) | (17) | (26) |
| (% serv.) | (25) | (28) | (35) | (26) | (29) |
| III (WE/JANZ) | 0.47 | 0.78 | 1.00 | 0.69 | 0.84 |
| (% elec.) | (18) | (28) | (41) | (28) | (37) |
| (% serv.) | (14) | (15) | (19) | (15) | (17) |
| IV (LA) | 0.031 | 0.11 | 0.26 | 0.10 | 0.21 |
| (% elec.) | (23) | (33) | (48) | (28) | (43) |
| (% serv.) | (10) | (12) | (15) | (12) | (20) |
| V (Af/SEA) | 0.028 | 0.12 | 0.30 | 0.11 | 0.25 |
| (% elec.) | (14) | (19) | (32) | (16) | (22) |
| (% serv.) | (9) | (12) | (16) | (10) | (12) |
| VI (ME/NAf) | 0.015 | 0.06 | 0.18 | 0.05 | 0.12 |
| (% elec.) | (7) | (22) | (43) | (19) | (31) |
| (% serv.) | (7) | (19) | (32) | (18) | (29) |

*The figures in this table refer only to the demand of commercial energy. These figures have been arrived at after taking into account the requirements of households that are/would be met by noncommercial fuels.

In 1975 there were 266 million homes in Regions I and III, 45 percent of which were centrally heated houses and apartments. There were on average 3.0 persons per household. Housing construction in the scenarios is assumed to be tied to the low population growth, allowing for further reductions in the assumed average number of persons per household by 2030: to 2.24 in Region I, and to 2.56 in Region III. Almost all new residential dwellings are assumed to be centrally heated; many are also air-conditioned. In these two regions by 2030 about 90 percent of dwellings will be centrally heated in the scenarios, compared to 45 percent currently. Air-conditioning will be available for 30–40 percent of dwellings, as against 12 percent in 1975.

In Regions IV, V, and VI taken together, the number of residential dwellings reaches about 1,130 million by 2030, from 360 million in 1975, with persons per household dropping from 5.22 to 4.16. As most of these regions are warm, space heating requirements are relatively small; only about 25 percent of dwellings require space heat. By 2030, 17 to 19 percent are assumed to use space heat, compared to 11 percent in 1975.

Service sector floor area increases fairly rapidly in Regions I and III, reflecting the high growth of the total service sector. By 2030, these regions will have from 1.7 to 2.1 times as much building area in use, and to be energy-serviced, as in 1975. In Region II the increase is even larger, from 3.2 to 4.0 times. Two main factors – higher population growth, and improvement in the working conditions of service sector employees – cause the growth in service sector activity in developing regions to be even greater than in developed regions. By 2030 service sector floor area in these regions is about 6.0 to 7.5 times that in 1975.

TABLE 25 Projected useful energy requirements in households ($10^3$ kWhr(e)/household/year).

| Region | Cooking | Space/ water heating | Air-conditioning | Misc. elec. appl. |
|---|---|---|---|---|
| *1975* | | | | |
| I (NA) | 1.2 | 25.3 | 1.0 | 3.9 |
| II (SU/EE) | 1.2 | 11.9 | 0 | 0.9 |
| III (WE/JANZ) | 1.3 | 9.5 | 0 | 2.0 |
| IV (LA) | 1.9 | 1.0 | 0 | 0.7 |
| V (Af/SEA) | 1.2 | 0.05 | 0 | 0.05 |
| VI (ME/NAf) | 1.9 | 0.8 | 0.01 | 0.2 |
| *2030 – High scenario* | | | | |
| I (NA) | 1.2 | 18.2 | 2.0 | 8.0 |
| II (SU/EE) | 1.2 | 14.4 | 0.2 | 5.0 |
| III (WE/JANZ) | 1.3 | 12.8 | 0.5 | 6.0 |
| IV (LA) | 2.1 | 2.9 | 0.4 | 3.4 |
| V (Af/SEA) | 1.4 | 0.2 | 0.02 | 0.5 |
| VI (ME/NAf) | 2.1 | 3.8 | 0.7 | 3.3 |
| *2030 – Low scenario* | | | | |
| I (NA) | 1.2 | 18.2 | 1.7 | 6.3 |
| II (SU/EE) | 1.2 | 13.6 | 0.2 | 3.0 |
| III (WE/JANZ) | 1.3 | 11.4 | 0.4 | 4.5 |
| IV (LA) | 2.1 | 2.3 | 0.2 | 2.2 |
| V (Af/SEA) | 1.4 | 0.1 | 0.01 | 0.3 |
| VI (ME/NAf) | 2.1 | 3.1 | 0.4 | 1.2 |

NOTE: Useful energy is expressed as electricity equivalent. Figures here are averages for all dwellings within a region.

Tables 25, 26, and 27 report some of the energy consumption figures associated with the household/service sector activity levels just cited. It is readily apparent from these tables that the largest energy-using device in buildings in developed regions is the space itself. Space heating, and to a lesser extent, air-conditioning, overwhelm other needs in residences; in service sector buildings, energy consumption due to electrical appliances is also very high. In Regions I and III, about 60 percent of useful energy in buildings goes to heating the inside air; in the scenario projections here this number decreases to 40–50 percent, as various energy-reducing measures are introduced.

Improved insulation in homes, old and new, can reap substantial reductions in energy use. In the scenarios insulation improvements in new buildings and retrofit of pre-1975 dwellings are assumed to reduce the heat losses in dwellings in Regions I, II, and III quite significantly. Retrofitting of the pre-1975 housing stock is assumed to reduce their heat losses by 20–30 percent over the next 50 years. Post-1975 dwellings are already designed to have 10–15 percent lower heat losses today; according to the assumptions used here, by 2030 the average heat losses of all post-1975 dwellings would be only 50 percent of those in 1975. Further gains are difficult beyond certain initial savings. Rising prices and an assumed increasing public awareness of energy uncertainties (plus a fair measure of government-instituted standards) are assumed to lead to these results.

TABLE 26 Household use of electricity, 1975 and scenario assumptions ($10^3$ kWhr(e)/household).

| Region | 1975 | High scenario 2000 | High scenario 2030 | Low scenario 2000 | Low scenario 2030 |
|---|---|---|---|---|---|
| I (NA) total electricity | 9.4 | 13.0 | 15.0 | 11.9 | 12.9 |
| (% thermal uses)* | (59) | (52) | (47) | (56) | (52) |
| II (SU/EE) total electricity | 1.2 | 3.9 | 6.5 | 3.0 | 4.3 |
| (% thermal uses) | (25) | (26) | (23) | (29) | (30) |
| III (WE/JANZ) total electricity | 3.1 | 6.0 | 9.1 | 5.3 | 7.1 |
| (% thermal uses) | (38) | (39) | (34) | (38) | (36) |
| IV (LA) total electricity | 0.7 | 1.9 | 4.2 | 1.4 | 2.7 |
| (% thermal uses) | (3) | (11) | (20) | (13) | (21) |
| V (Af/SEA) total electricity | 0.05 | 0.2 | 0.5 | 0.1 | 0.3 |
| (% thermal uses) | (1) | (4) | (8) | (3) | (11) |
| VI (ME/NAf) total electricity | 0.2 | 1.2 | 4.3 | 0.9 | 1.8 |
| (% thermal uses) | (9) | (22) | (23) | (19) | (33) |

*Thermal uses include air-conditioning.

NOTE: Only for Region I (NA) were sufficient statistics available; for other regions estimates come from partial data and/or data for selected countries.

Consumption of electricity per household for specific uses (lighting, electrical appliances) is a direct assumption; consumption for thermal uses results from separate assumptions on useful energy consumption for space heating, water heating, cooking, and air-conditioning and from assumed penetration of electricity into these markets.

Electricity used for appliances has grown by great leaps and bounds in recent years, usually much faster than rises in real income. Increased disposable income has to date seemed to go in rather large shares to "extras" such as dishwashers, color televisions, clothes dryers. In Region I, and to some extent in Regions II and III, some flattening of this growth curve is postulated – appliance ownership saturates, and their energy efficiencies improve in response to rising prices.

Relative increases in electricity consumption for household appliances (see Table 25) are much higher by 2030 in developing regions – 3 to 5 times 1975 levels in Region IV, 5 to 10 times in Region V, and 6 to 17 times in Region VI – mainly because the present levels are so low. Most houses which use electricity at all in these regions today use it only for lighting and a bare minimum of other activities.

Another factor which is expected to play an important role in the future energy requirements of buildings in both the developed and developing regions is air-conditioning. Until now the extensive use of air-conditioning has been limited to Region I; scenario assumptions here project by 2030 considerable use of air-conditioning in several other world regions as well (see Tables 25 and 27).

At present the useful thermal energy requirements in the household/service sector are met essentially by fossil fuels and electricity in the developed regions and by fossil fuels and noncommercial energy in the developing regions. The scenario assumptions of Table 9.3.3 (Groups 3.3d and 3.3e) concerning the future use of noncommercial fuels; efficiency improvements in the use of all fuels; and penetration of electricity, soft solar, district heat, and heat pumps lead to the final energy demand patterns shown in Table 28. There, the large reliance on district heat in Region II is simply a logical extension of the present situation. Also, the higher fossil, and low electric, shares in developing regions

TABLE 27 Useful energy* projections for service sector.

| Region | Service sector working area ($10^9 m^2$) | Space/water heating | Air-conditioning | Misc. elec. appl. |
|---|---|---|---|---|
| *1975* | | | | |
| I (NA) | 2.72 | 270 | 22 | 120 |
| II (SU/EE) | 1.50 | 256 | 0 | 40 |
| III (WE/JANZ) | 3.00 | 110 | 2 | 40 |
| IV (LA) | 0.60 | 12 | 2 | 25 |
| V (Af/SEA) | 1.25 | 1 | 0 | 15 |
| VI (ME/NAf) | 0.18 | 20 | 2 | 15 |
| *2030 – High scenario* | | | | |
| I (NA) | 5.00 | 227 | 33 | 150 |
| II (SU/EE) | 6.65 | 186 | 12 | 100 |
| III (WE/JANZ) | 7.26 | 96 | 8 | 104 |
| IV (LA) | 3.20 | 19 | 16 | 65 |
| V (Af/SEA) | 9.40 | 2 | 2 | 38 |
| VI (ME/NAf) | 2.54 | 52 | 20 | 100 |
| *2030 – Low scenario* | | | | |
| I (NA) | 3.79 | 225 | 28 | 136 |
| II (SU/EE) | 4.75 | 186 | 8 | 80 |
| III (WE/JANZ) | 5.99 | 95 | 6 | 89 |
| IV (LA) | 3.41 | 22 | 14 | 66 |
| V (Af/SEA) | 6.90 | 2 | 1 | 33 |
| VI (ME/NAf) | 1.84 | 52 | 12 | 85 |

*Useful energy is expressed as electricity equivalent (kWhr(e)/$m^2$).

TABLE 28 Shares of energy sources in the household/service sector heat market (% of total useful thermal energy).

| | High scenario | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | | | | | 2030 | | | | |
| Region | NCE* | FF | EL | DH** | SS | NCE | FF | EL | DH | SS |
| I (NA) | 0 | 68 | 24 | 0 | 8 | 0 | 56 | 31 | 0 | 13 |
| II (SU/EE) | 4 | 44 | 6 | 43 | 3 | 3 | 22 | 10 | 60 | 5 |
| III (WE/JANZ) | 0 | 73 | 15 | 6 | 6 | 0 | 55 | 21 | 13 | 11 |
| IV (LA) | 18 | 72 | 3 | 1 | 6 | 14 | 57 | 9 | 8 | 12 |
| V (Af/SEA) | 37 | 63 | 0 | 0 | 0 | 26 | 70 | 2 | 0 | 2 |
| VI (ME/NAf) | 3 | 94 | 2 | 0 | 1 | 2 | 86 | 5 | 2 | 5 |

*In 1975, noncommercial energy share is estimated to be 7, 39, 68, and 9 percent in Regions II, IV, V, and VI, respectively. The Low scenario shares are quite similar to those in the High scenario.

**The share of district heat in Region II was already 25 percent in 1975.

NCE = noncommercial energy sources; FF = fossil fuels (for Regions IV, V, and VI, this column includes the fossil fuel equivalent of charcoal/wood and biogas to be supplied as commercial fuel); EL = electricity; DH = district heat; SS = soft solar.

than in developed reflect the end-use patterns typical in buildings in these two kinds of regions.

The extent of conservation implied in these projections may be judged from the fact that use of heat pumps in electrical heating to the extent of 40–50 percent in Regions I, II, and III and 12 percent in Regions IV and VI as well as efficiency improvements of 10 to 25 percent in the use of fossil fuels in different world regions, have been assumed possible by 2030.

In spite of the unfavorable cost economics of present soft solar devices, we have introduced fairly aggressive buildup rate assumptions for soft solar systems in the household/service sector in both the developed and the developing regions (see Table 9.3.3, Group 3.3d). For example, it has been assumed that 50 percent of all new (post-1975) single-family centrally heated homes and low rise service sector buildings will install solar heating systems (the assumptions are 30 percent for Region II and 20 percent for Region VI). These systems will be 50 to 80 percent solar – that is, requiring backup (oil, electric, gas) for 20 to 50 percent of the time. Further, it is assumed that by 2030 30–40 percent of all the households in Regions I, III, IV, and V, and 15–20 percent in Regions II and VI, would be using solar water heating systems. With these assumptions one finds by 2030 that soft solar devices would support 10–11 percent of the household/service sector's space and water heating demand in the developed Regions I, II, and III and about 14 percent of the corresponding demand in the developing Regions IV, V, and VI, in both the High and the Low scenarios. The shares of soft solar in the total useful thermal energy demand (including cooking and air-conditioning requirements) will be even lower, as shown in Table 28 for the High scenario.

The rather optimistic buildup rate assumptions for soft solar used in this assessment serve to explore a reasonable upper bound to what they could contribute in the energy mix. However, the ultimate soft solar contribution seems to be constrained by the size of the market – the demands for space and water heat in detached houses or low-rise service sector buildings are not excessive. Moreover, in the developing regions, a large fraction of the useful heat demand of the household/service sector originates from cooking requirements. This fraction was about 82 percent in 1975 and remains as high as 59–64 percent by 2030. Further, in these regions most of the dwellings that need space heating are heated with only detached room heaters and this practice is expected to continue – although at a lower level – in spite of increased income levels, as the heating seasons and requirements are generally small.

### *5.3.2 Electricity Demand*

In the developed regions, electricity demand has been growing rapidly – significantly faster than GDP and faster than the demand for other energy forms. High end-use efficiency, flexibility, and ease of control make this energy form economically more attractive than other energy carriers, such as coal or even oil and gas, which in general require a larger technological effort at the point of end-use. On the other hand, thermal generation of electricity involves large conversion losses, and the expected price rises for primary fuels will make it necessary to economize its use* – to restrict it as much as possible to essential uses.

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*The impact of higher generation costs can be judged from the significantly lower levels of electrification in countries with predominantly thermal generation (typically 10–14 percent) than in countries with great hydropower potential (e.g., Norway with about 20 percent of final energy consumption).

In view of these considerations, our assumptions concerning penetration of electricity in the household/service sector heat market have been fairly conservative. In the market-economy developed regions I + III, it is assumed that price increases for electricity in general and the problem of large peaks in the winter season in particular would discourage consumers to use electricity as the main energy carrier for heating. In the centrally planned Region II, the emphasis has been, and probably will be, to provide space heat and hot water with district heat, either from combined heat and power plants, or from boiler plants which allow an economical use of low-grade fuels. As a result of the various assumptions, specific uses of electricity in the household/service sector in the developed regions grow by a factor of 4.8 and 3.4 between 1975 and 2030 in the High and Low scenarios, respectively; with respect to thermal uses of electricity, the two scenarios differ only modestly, with factors of growth between 1975 and 2030 of 3.1 and 2.8, respectively (Table 29).

In industry, the differences in the level of electrification between the three developed regions are not as great as in the household/service sector (see Vigdorchik 1976). Unfortunately, the lack of data does not permit a separation of thermal uses (furnaces, small boilers, etc.) from specific uses (lighting, electric drives, electrolysis, etc.). As indicated in Table 29, only the incremental electricity penetration into thermal uses above the present levels is considered. Data for France and Austria indicate that about 10 percent of the useful thermal energy demand is supplied by electricity. If this figure is applied to the developed regions I + II + III, the resulting estimates of thermal and specific uses of electricity in industry are 94 and 217 GWyr/yr in 1975, which corresponds to a ratio of 1:2.3.

For the scenarios, no change was assumed in the energy intensity of industry with respect to specific electricity requirements. While in the past there was an increase in almost all industry sectors, mainly as a result of increasing automation. However, the refined control mechanisms that are possible through the use of microprocessors will help to rationalize processes better and perhaps allow a reduction in energy use despite more automation. No significant further penetration into thermal uses was assumed – following the general guideline to minimize the use of primary fuels. However, the situation in industry is different from that in the household/service sector. In the latter sector the major share of thermal energy demand is in the low-temperature range, where electricity offers more convenience, but requires a larger amount of primary fuels than direct combustion of fossil fuels. In industry, about 40 percent of the thermal energy demand is in the high-temperature range, and in these applications electricity is in some cases even superior from an energetic point of view, in addition to being economically advantageous. In the light of these considerations, the projections of industrial electricity demand are probably on the conservative side. "Specific uses" in the three developed regions increase by factors of 4.2 and 3.7 in the High and Low scenarios, respectively, while the total industrial electricity use increases by factors of 4.9 and 3.0, respectively. Assuming that about one-third of the electricity demand for the so-called "specific uses" would actually be for thermal uses, electricity would cover about 21–24 percent of the useful thermal energy demand in 2030. Since it would mainly be used in the high-temperature range, this means that by 2030 about 50–60 percent of the high-temperature demand would be supplied by electricity.

The situation of the developing regions (IV + V + VI) could be compared to that in the developed regions several decades previous, when large areas had no access to

TABLE 29 Thermal energy and electricity demand in the two scenarios (GWyr/yr).

| | Developed regions (I + II + III) | | | | | Developing regions (IV + V + VI) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | High scenario | | Low scenario | | | High scenario | | Low scenario | |
| | 1975 | 2000 | 2030 | 2000 | 2030 | 1975 | 2000 | 2030 | 2000 | 2030 |
| Useful thermal energy demand: | | | | | | | | | | |
| Industry | 939 | 1,775 | 2,672 | 1,504 | 1,894 | 105 | 484 | 1,351 | 339 | 694 |
| Household/service | 781 | 1,170 | 1,457 | 1,091 | 1,306 | 67 | 163 | 344 | 157 | 316 |
| Total | 1,720 | 2,945 | 4,129 | 2,595 | 3,200 | 172 | 647 | 1,695 | 496 | 1,010 |
| Of which supplied by electricity: | | | | | | | | | | |
| Industry* | 0 | 85 | 215 | 60 | 113 | 0 | 10 | 93 | 7 | 48 |
| Household/service | 75 | 164 | 234 | 152 | 210 | 0 | 3 | 16 | 3 | 14 |
| Total | 75 | 249 | 449 | 212 | 323 | 0 | 13 | 109 | 10 | 62 |
| Specific uses of electricity: | | | | | | | | | | |
| Industry | 311 | 694 | 1,305 | 563 | 828 | 39 | 235 | 763 | 168 | 409 |
| Household/service | 153 | 397 | 738 | 328 | 520 | 11 | 68 | 264 | 51 | 161 |
| Total | 464 | 1,091 | 2,043 | 891 | 1,340 | 50 | 303 | 1,027 | 219 | 570 |
| Electricity use for transportation | 16 | 46 | 116 | 41 | 87 | 1 | 4 | 35 | 3 | 24 |

*Only electricity penetration into thermal uses above the present level is considered, because a separation of thermal and specific uses in 1975 was not possible due to lack of data. A very rough estimate for the developed regions could be 10 percent of useful thermal energy demand, or 90–100 GWyr/yr.

electricity and many households used electricity for lighting. As a result of increasing rural electrification and higher levels of per household electricity consumption as well as due to high population and industrial growth rates assumed for the developing regions, the two scenarios imply a rapid increase of electricity demand during the study period:

Specific uses, household/service sector: X24(H)/X15(L)
Total uses, household/service sector: X25(H)/X16(L)
Specific uses, industry: X20(H)/X10(L)
Total uses, industry: X22(H)/X12(L)

In the case of developing regions, air-conditioning could cause a rapid increase in electricity demand. Most of the population in the developing Regions IV, V, and VI lives in warm climatic zones and the use of comfort air-conditioning may be expected to increase with increasing per capita income. In the scenarios considered here the average use of air-conditioning per dwelling and per square meter of service sector floor area in 2030 in Regions IV (LA) and VI (ME/NAf) is assumed to become comparable to that envisaged for the developed Regions I, II, and III (see Tables 25 and 27). However the air-conditioning requirements (per dwelling or per square meter of service sector floor area) of Region V (Af/SEA) are assumed to be an order of magnitude smaller, despite a latent demand, in view of the low income levels that will persist in this region even 50 years from now.

## 6 CONCLUDING REMARKS

The projections of final energy demand till 2030 for six out of the seven comprehensive world regions considered in IIASA's energy study (Energy Systems Program Group 1981) and the various underlying assumptions have been discussed at some length. In evaluating them one has to appreciate that projecting energy demand in a medium- to long-term frame is a fundamentally complex issue – full of uncertainties and pitfalls.

One gets a feeling of the difficulties and uncertainties involved in such an undertaking by looking at the various medium- to long-term energy demand projections available for one country, i.e., the US, whose present pattern of energy consumption is best understood and the relevant historical data of which are best documented. A number of recent primary energy projections for the US are plotted in Figure 7. The wide variation in these projections aptly illustrates the difficulties involved. Obviously, the uncertainties increase as the projections extend to larger world regions covering several countries, given an availability of data that is much less satisfactory than for the US. Nonetheless, estimates of future energy requirements of the various world regions are essential for us to appreciate the kind and size of problems the world may have to face in the wake of dwindling global conventional fuel resources and in order to be prepared to meet the challenge.

The assessments of final energy demand reported here represent such an effort. Of course, they are not predictions or forecasts; in our judgment, they simply describe a range of realistic evolutions of future energy demand in various world regions that are consistent with a plausible range of world economic development and population growth.

The world's energy demand increased more or less exponentially between 1950 and 1975 at an average growth rate of 5 percent per year (see e.g., Doblin 1979). Obviously,

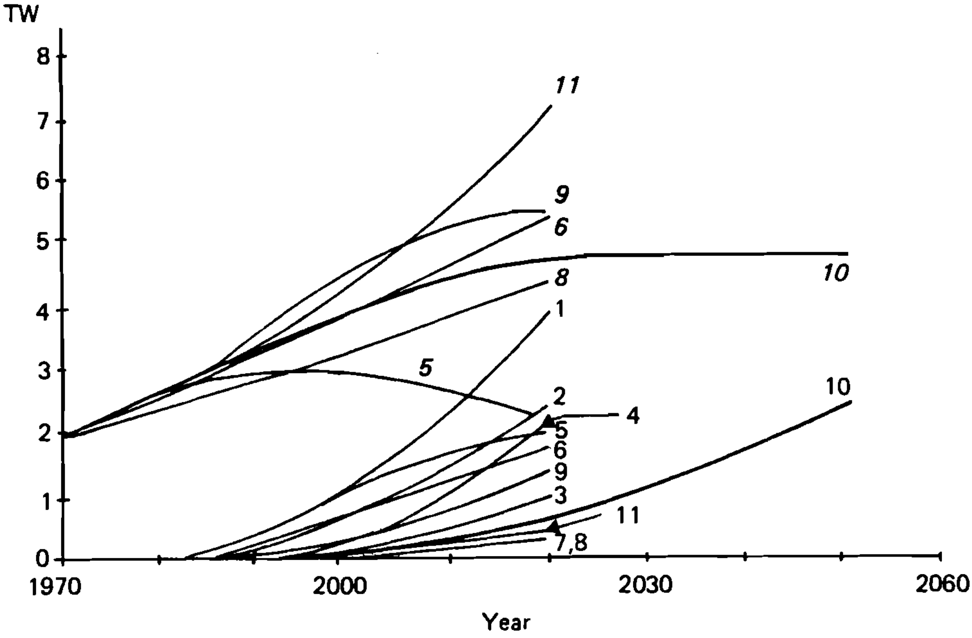

FIGURE 7 Some recent projections of primary energy demand and potential solar shares ofr the US. Italic numbers describe projections of total energy demand; roman numbers indicate total energy demand potentially available from solar energy sources: (1) MITRE (1973), (2) Morrow (1973) "maximum solar", (3) Morrow (1973) "minimum solar", (4) Wolf (1974), (5) Lovins (1976), (6, 7, 8) Renyl et al. (1976), (9) ERDA 49 (1975), CONAES (1977), (10) Weingart and Nakicenovic (1979), (11) Beller ed. (1975) "future energy reference system".

this trend cannot continue in view of the limited resources of conventional fuels. Although there are sources of energy – solar and nuclear (through breeding and fusion) – that promise virtually unlimited supply, the present status and cost economics of these sources is such that they may, at best, be expected to play only a minor role in the next 15–50 year period. Therefore, energy conservation leading to a shift away from the exponential energy growth trend of the last 30 years is indispensable. However, significant energy conservation is possible only in the most highly developed countries; most of the population in the developing world still lives at levels of energy consumption close to subsistence and will need increasing amounts of energy to improve. The assessment of energy demand reported here is based on what we would consider optimistic, though not unrealistic, assumptions about measures of energy conservation and possible technological improvements.

The extent of energy savings embodied in the two scenarios can be seen in Figures 8a and 8b, where final energy per unit of GDP is plotted against GDP per capita for Regions I through VI. There the ratio of final energy demand to GDP is seen to continue to decrease for the developed Regions I, II, and III in line with the historical trends. On the other hand, the ratio continues to increase, at least initially, for all the developing regions, again in line with the historical trends, but flattens off later and even starts to fall in Regions IV and VI. These different trends in the developed and the developing regions are characteristic of economies that have already reached a high level of industrialization, but are still in the process of building up their industrial infrastructure.

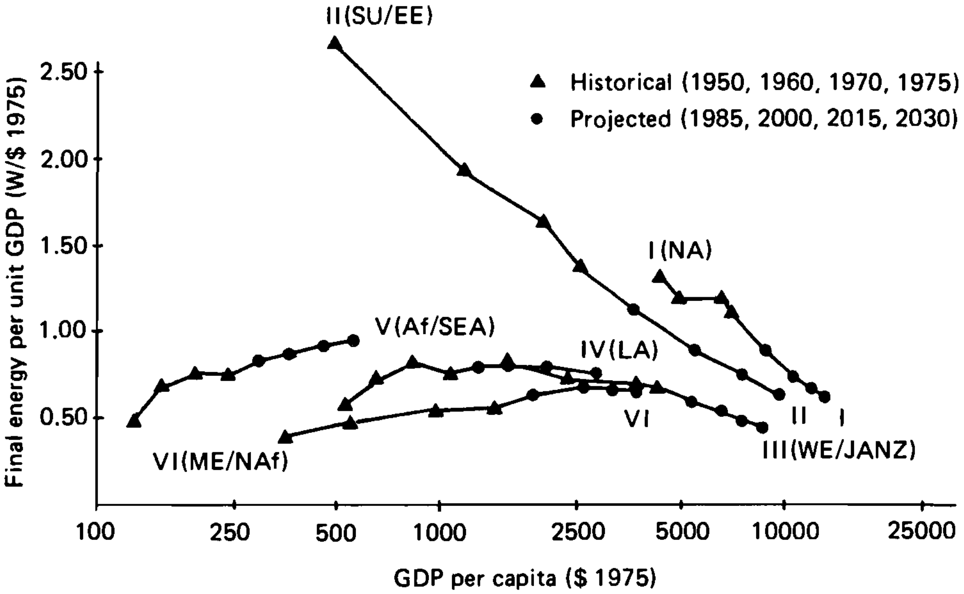

FIGURE 8a Energy intensity in different world regions (High scenario).

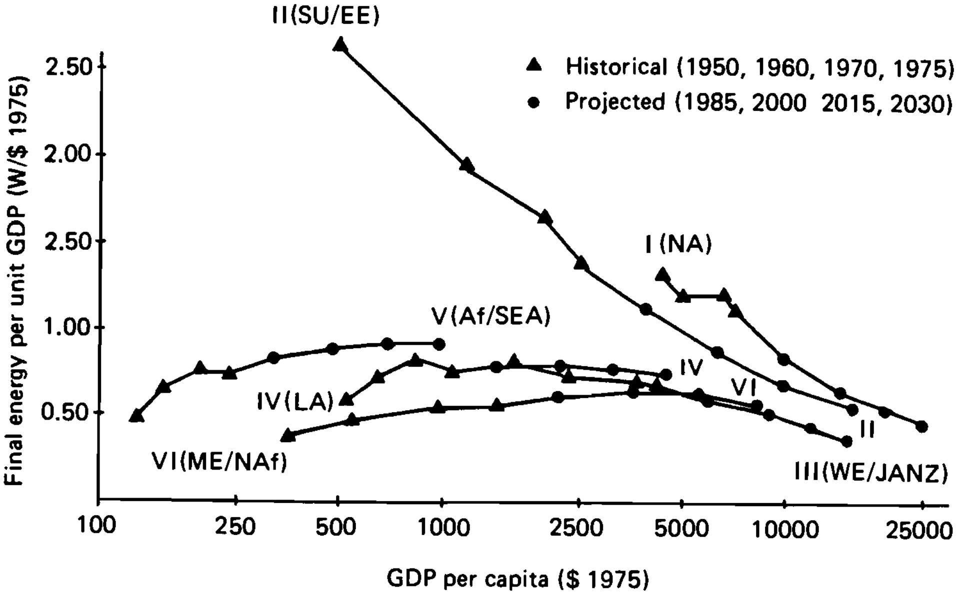

FIGURE 8b Energy intensity in different world regions (Low scenario).

Globally speaking, the curves of Figures 8a and 8b imply a reduction of final energy per dollar of GDP from 0.91 in 1975 to 0.53 and 0.62 in 2030 for the High and the Low scenarios, respectively. If only the developed Regions I, II, and III are considered, the improvement is even more impressive: final energy per dollar of GDP decreases from 0.95 in 1975 to 0.45 and 0.55 over a period of 55 years. By far the largest improvement is seen in Region II (SU/EE), where the overall conservation resulting from various scenario assumptions amounts to 61 and 54 percent. The corresponding figures for Region I are 59 and 44 percent and for Region III (WE/JANZ) 45 and 33 percent. These improvements, seen in the light of real price increases of 3.0 and 2.4 times the prices in the recent past (see Energy Systems Program Group 1981, Chant 1981) appear quite pronounced but not unrealistic. Some measures behind this trend have been reported here in detail. Indicators such as automobile efficiency, average transport load factors, home insulation, structural changes in industry and others have been cited to illustrate the extent of the energy-using improvements assumed.

Another measure of the efficiency improvements assumed in the scenarios can be derived by calculating the final energy that would result by 2030 if the historical 1950–1975 final energy-to-GDP elasticity were applied for 1975 to 2030. Table 30 shows the differences between final energy calculated in this way and the final energy projections of the High and the Low scenarios.

TABLE 30 Final energy in the two scenarios compared to final energy calculated with historical elasticities (2030).

| Region | High scenario (GWyr/yr) | With historical $\epsilon_f$ (GWyr/yr) | Difference** (%) | Low scenario (GWyr/yr) | With historical $\epsilon_f$* (GWyr/yr) | Difference** (%) |
|---|---|---|---|---|---|---|
| I (NA) | 3,665 | 6,921 | 47 | 2,636 | 4,036 | 35 |
| II (SU/EE) | 4,114 | 5,355 | 23 | 2,952 | 3,850 | 23 |
| III (WE/JANZ) | 4,375 | 6,037 | 28 | 2,987 | 3,761 | 21 |
| IV (LA) | 2,641 | 4,385 | 40 | 1,656 | 2,481 | 33 |
| V (Af/SEA) | 3,175 | 6,900 | 54 | 1,876 | 3,121 | 40 |
| VI (ME/NAf) | 1,620 | 2,590 | 37 | 850 | 1,015 | 16 |
| Total of I to VI | 19,590 | 32,188 | 39 | 12,957 | 18,264 | 29 |

*Calculated using historical (1950–1975) final energy-to-GDP elasticity ($\epsilon_f$) for each region.

**Calculated as final energy using historical $\epsilon_f$ minus IIASA scenario projection divided by final energy using historical $\epsilon_f$.

Savings of roughly 20 to 50 percent occur in each region. The demand reductions in Regions I to VI through conservation measures embodied in the two IIASA scenarios thus represent a net final energy saving of 5.3 to 12.6 TWyr/yr by 2030.

These amounts are certainly substantial. They underscore the aggressive conservation measures assumed in the scenarios. They reflect the belief that vigorous action to increase energy efficiency and to improve energy productivity is a necessity in any energy strategy – short-, medium- or long-term. Without such improvements, the adequate supply of energy necessary to meet the demand at the levels of world economic and population growth assumed would probably run into serious difficulties, and the two IIASA energy supply scenarios (Energy Systems Program Group 1981) might not have proved to be feasible.

The appropriate energy supply strategies corresponding to the two final energy demand scenarios discussed in this report have been described in detail in the Energy Systems Program Group (1981). They indicate that meeting the global requirements of energy will become increasingly more difficult with time. Still the demand can be met with the help of technologies which are either in hand or expected to be commercially available (at economical costs) in the near future. The two IIASA supply scenarios imply provision of 22.4 TW to 35.7 TW of primary energy globally* in the year 2030. This is by mining 6.5 to 12.0 TWyr/yr of coal, as against 2.3 TWyr in 1975, (of which 52 percent to 56 percent will be required for making synthetic liquid fuel), by exploiting 1.6 to 3.5 TWyr/yr of unconventional oil reserves of tar sand, shale, heavy crude, and by generating 1.8 to 2.9 TWyr of electricity through nuclear reactors (of which 1.2 to 1.8 TWyr will be from fast breeder reactors). All this would call for tremendous efforts and heavy investments – the investment required for building the energy supply infrastructure will increase to a level of about 4.5 percent of the gross world product (as against 2.5 percent in 1975). One, therefore, wonders if it is possible to cut down the energy demand for a given economic growth much beyond the level envisaged in the present assessment by invoking additional conservation. In order to assess the implications of extreme conservation measures, a scenario was developed for Regions I (NA) and III (WE/JANZ) (see Energy Systems Program Group 1981) that gave final energy demand in 2030. This was lower by 32 percent than the Low scenario demand of Region I and 45 percent lower than Region III (implying zero final energy growth between 1975 and 2030 for Regions I and III taken together) for the same economic growth as in the case of the Low scenario. Possible percentage reductions in total and sectoral final energy demand as well as in demand by fuel types for the two regions, resulting from incorporating extreme conservation in the Low scenario, are listed in Table 31.

What such an extreme conservation would imply may be judged to a certain extent by comparing some major assumptions of the Low scenario and the Extreme Conservation scenario listed in Table 32. The Extreme Conservation scenario differs from the Low scenario essentially in the following features: a large shift in the structure of GDP formation towards services and within the manufacturing sector away from energy-intensive heavy industries and towards less energy-intensive construction of machinery and equipment; reduced activity level projections, particularly in the transportation sector; higher efficiency improvements, particularly for activities pertaining to the industry and household/service sectors; reduced or phased out penetration of electricity into thermal uses; and finally, reduced use of electrical appliances in dwellings, and of comfort heating and air-conditioning in the household/service sector buildings.

In some cases, changes in important energy-using activities were rather modest because, it was felt, sufficiently aggressive changes were already incorporated into the Low scenario. For example, automobiles were assumed to reach an average efficiency of 7.4 l/100 km (32 mpg) in Region I by 2030 in the Low scenario, from a 1975 average

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*Including the primary energy requirements of Region VII (China and Centrally Planned Asian Economies) which are projected as 2–3 TW and 4.5 TW for the Low and High scenarios, respectively.

TABLE 31 Percentage reduction in an Extreme Conservation scenario compared to the Low scenario final energy demand in 2030, Regions I (NA) and III (WE/JANZ).

| | Percent reduction required in | | |
|---|---|---|---|
| | Region I | Region III | Regions I and III |
| Total final energy | −32 | −45 | −39 |
| *By sector* | | | |
| Transportation | −40 | −45 | −43 |
| Industry | −38 | −54 | −47 |
| Household/service | −8 | −28 | −19 |
| *By energy form* | | | |
| Substitutable fossil fuels* | −18 | −40 | −29 |
| Centrally supplied heat** | na | −34 | −34 |
| Soft solar | −18 | −35 | −26 |
| Electricity | −52 | −55 | −54 |
| Motor fuel | −37 | −40 | −38 |
| Coke and feedstocks | −27 | −56 | −45 |

*Substitutable fossil fuels are thermal uses of oil, gas, and coal.
**Centrally supplied heat is steam and hot water from district heat or cogeneration plants.
na: Not applicable.

TABLE 32 Some major assumptions for an Extreme Conservation case compared to those of the Low scenario.

| | Region I | | | Region III | | |
|---|---|---|---|---|---|---|
| | | 2030 | | | 2030 | |
| | 1975 | Low scenario | Extreme Conservation | 1975 | Low scenario | Extreme Conservation |
| *Macroeconomics, lifestyle* | | | | | | |
| Manufacturing (% of GDP) | 24.5 | 23.8 | 20 | 33.6 | 29.7 | 20 |
| Services (% of GDP) | 64.8 | 65.8 | 69.6 | 48.5 | 55 | 64.7 |
| Basic materials (% of manufacturing–VA) | 24.8 | 23.2 | 20 | 33 | 29.4 | 20 |
| Machinery and equipment (% of manufacturing–VA) | 43.2 | 47 | 50.2 | 42 | 47.1 | 55 |
| *Intercity passenger transportation* | | | | | | |
| Distance traveled per person per year (1,000 km) | 10 | 15 | 10 | 7.5 | 10 | 7.5 |
| Persons per car | 2 | 1.9 | 2 | 5.21 | 3.20 | 4 |
| Distance driven per car per year, intercity (1,000 km) | 7 | 7.8 | 5 | 5 | 5.6 | 5 |
| Bus (% of public transportation) | 15 | 12 | 30 | 35 | 29 | 35 |
| Train (% of public transportation) | 5 | 5 | 20 | 50 | 56 | 60 |
| Plane (% of public transportation) | 80 | 83 | 50 | 5 | 15 | 5 |
| *Dwellings* | | | | | | |
| Electrical use for appliances (1,000 kWhr(e)/dwelling) | 3.85 | 6.25 | 3.85 | 1.95 | 4.50 | 2.20 |
| Useful energy for air-conditioning per dwelling (1,000 kcal) | 4,472 | 5,800 | 4,472 | | 3,000 | |
| Dwelling with air-conditioning (%) | 39 | 50 | 20 | 0 | 20 | 0 |

NOTE: These assumptions are selected from an array of changes. They both represent the largest changes and have the most energy-reducing impact. In some instances (e.g., automobile efficiency or home insulation) the assumptions for the Low scenario were regarded as sufficiently rigorous so that only rather minor further improvements could be introduced into the Extreme Conservation case.

of 17.1 l/100 km (14 mpg). This projection to 2030 was unchanged for the Extreme Conservation scenario. In Region III, automobile efficiency was assumed to improve from about 9.9 l/100 km in 1975 to about 7.2 l/100 km in 2030 in the Low scenario and to about 5.5 l/100 km in the Extreme Conservation scenario. Similarly, improvements in the technical efficiency of fossil fuel use from the Low scenario to the Extreme Conservation scenario could not be too substantial, given the already high efficiencies assumed for the former.

Whereas this exercise indicates that reduction of energy demand, at least in the developed regions, by some 30–45 percent below the levels envisaged in the present assessment may be possible through extreme conservation measures, it is not clear as to what actions (energy price increases, tax benefits, early amortization allowances etc.) would be required to spur such changes. In our opinion, therefore, it will not be prudent to rely for future energy planning on such extreme conservation possibilities which are rather unlikely to happen.

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B. Lapillonne, who implemented the MEDEE-2 model at IIASA, established the base year data set for the US (about 90 percent of Region I), and also helped establish the base year values for Region III (Western Europe, Japan, Australia, and New Zealand).

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# APPENDIXES

## APPENDIX A: THE SEVEN WORLD REGIONS OF THE IIASA ENERGY SYSTEMS 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: Western Europe, Japan, Australia, 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
Luxembourg
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 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, People's Republic of North
- Laos, People's Democratic Republic of
- Mongolia
- Vietnam, People's Republic of

# APPENDIX B: EQUATIONS AND VARIABLE DEFINITIONS OF MEDEE-2 (IIASA VERSION)

## APPENDIX B1: CALCULATION OF ENERGY DEMAND IN MEDEE-2

An outline of MEDEE-2 has already been presented in the main text of this report (see Section 3). In general, the overview given is sufficient to understand the approach. The computer model itself is just one part of a three-stage process, which includes (1) a detailed analysis of the present energy consumption pattern in the country or region under consideration; (2) an analysis of past trends in economic, social and technological factors with an important influence on energy demand; and (3) the construction of scenarios describing alternative future evolutions of these factors and the calculation of energy demand implied by these scenarios*. The last step is facilitated by the computer model which serves both as a framework to formulate scenarios and as an accounting tool to evaluate the energy demand evolution corresponding to a given scenario.

The computer model is rather simple and mechanistic. It relies almost exclusively on exogenous information, and dependencies between the various factors are in general not formalized – it is left to the user to ensure that his projections are reasonable and consistent. This is certainly a major shortcoming of the model, and in any application to a single country efforts will have to be made to reduce the number of exogenous variables and to internalize the projection of their future evolution by means of structural assumptions. It is doubtful, however, that such a formal approach would have been successful in this global study which considers world regions rather than individual countries; available statistics would probably not allow the estimation and validation of complex relations with any statistical significance. Although the equations are mostly trivial they are summarized here in order to clarify how the various parameters affect the results**. This may also help to remove ambiguities about the scope of the model. A listing of both parameter and derived variables is added at the end of this Appendix; the parameter variables appear in the same sequence as in Tables 8 and 9, which contain a cross-regional comparison of the specific values assigned in the two scenarios.

### *Definition of Energy Use Categories*

MEDEE-2 distinguishes three broad "sectors" of energy use which are defined from a functional rather than from an institutional point of view; energy use for the production of goods is aggregated under the label "industry" – this includes agriculture, construction, and mining as well as manufacturing; energy used to transport goods or passengers is summarized under the label "transportation" – this includes commercial and public transportation as well as private transportation by car; energy used in dwellings and service sector buildings is summarized under the heading "household/service sector". Since MEDEE-2 deals only with final energy, it excludes by definition any internal energy

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*In order to limit the number of scenarios, only one trajectory needs to be considered for those factors showing a heavy trend that is likely to continue into the future. For other factors, that could depart significantly from past trends and/or present expectations – for example, due to saturation, or in reaction to higher energy prices, or as a result of regulations – a range of values must be considered if the uncertainty of future energy demand is to be captured.

**Parameter variables are typed in italics, other variables in roman.

use by energy production industries; energy use for such purposes is determined in the course of the energy supply calculation.

An important aspect for the assessment of future energy demand by form is the degree of substitutability between various sources. Therefore, a distinction is made between "specific uses", where substitutions are rather unlikely (e.g., electricity for lighting, motive power in stationary applications, electrolysis, etc.; liquid fuels for network-independent transportation; coke for pig-iron production; liquid fuels or natural gas as feedstocks), and *thermal energy* use where various energy sources can be used to meet the demand (e.g., fossil fuels, such as coal, oil, and gas; district heat; electricity; solar energy; other commercial fuels such as charcoal and biogas). Energy demand for specific uses is directly calculated in terms of final energy; thermal energy demand is first calculated in terms of useful energy* and then converted to final energy taking into account the fuel mix and the end-use efficiencies of the various energy sources.

### *Macroeconomic Indicators*

MEDEE-2 requires a fairly detailed picture of the expected macroeconomic situation as a background for the energy demand scenarios. Energy demand for the production and transportation of goods is directly linked to the value added (at constant prices) of the various sectors. Energy demand for "consumptive uses" such as in passenger transportation or in the household/service sector is not directly linked to monetary indicators but rather to physical factors; nevertheless relationships between activity levels in these sectors and macroeconomic indicators do exist, although they are not formalized within the computer model.

Six major economic sectors are distinguished in the model, namely *agriculture, construction, mining, manufacturing, energy*, and *services*; the manufacturing sector is further divided into four subsectors, namely *basic materials, machinery and equipment, nondurables*, and a *miscellaneous* category. The model allows calculation of the GDP formation, i.e., the value added generated by each sector, in either of two ways: (1) by specifying the structure of GDP formation directly; or (2) by estimating coefficients for a set of (linear) equations which determine the GDP contribution of each sector as a function of GDP expenditure.

The second approach can be chosen if time series of national accounts statistics are available which allow an estimation of the various coefficients. For the six world regions considered in this study, the available statistics were generally poor, and therefore the sectoral shares were entered directly as a scenario. Exports, imports and import duties, and government expenditures are not explicitly considered. On the level of world regions, this is not a serious simplification; for individual countries, however, foreign trade usually represents large shares of total GDP and should therefore be treated explicitly.

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*The term is used here in the sense of "equivalent electricity requirements". Efficiencies are expressed relative to those of electricity. By definition, electricity, district heat, and solar energy are accounted for with an end-use efficiency of 1.

*Variant (a)*
The GDP formation is entered exogenously:

- GDP formation by economic sector:

$$\begin{bmatrix} \mathrm{YAG} \\ \mathrm{YB} \\ \mathrm{YMIN} \\ \mathrm{YMAN} \\ \mathrm{YEN} \\ \mathrm{YSER} \end{bmatrix} = Y \cdot \begin{bmatrix} PYAG \\ PYB \\ PYMIN \\ PYMAN \\ PYEN \\ PYSER \end{bmatrix}$$

$$\mathrm{VAMAN} = \mathrm{YMAN}$$

- Value added by manufacturing subsectors:

$$\begin{bmatrix} \mathrm{VAIG} \\ \mathrm{VAM} \\ \mathrm{VAC} \\ \mathrm{VAMIS} \end{bmatrix} = \mathrm{VAMAN} \cdot \begin{bmatrix} PVAIG \\ PVAM \\ PVAC \\ PVAMIS \end{bmatrix}$$

where

$Y$ = Total GDP ($10^9$ \$1975)
$PYxxx$ = Relative contribution of a sector to total GDP (fraction)
$Yxxx$ = Absolute GDP contribution of a sector ($10^9$ \$1975)
$xxx$: AG = Agriculture
B = Construction
MIN = Mining
MAN = Manufacturing
EN = Energy
SER = Services
VAMAN = Total value added by manufacturing industries ($10^9$ \$1975)
$PVAxxx$ = Relative contribution of a subsector (fraction)
$VAxxx$ = Value added of a manufacturing subsector ($10^9$ \$1975)
$xxx$: IG = Basic materials (mostly intermediate goods)
M = Machinery and equipment (capital goods and durable consumer goods)
C = Nondurable (mostly consumer goods)
MIS = Miscellaneous

*Variant (b)*
The GDP formation is determined as a function of private consumption expenditures on durables, nondurables and services, and of investment expenditures on construction and

machinery and equipment. This option is chosen if (*PYAG*, . . . , *PYSER*) or (*PVAIG*, . . . , *PVAMIS*) are all zero.

- GDP expenditure:

$$\mathrm{GCF} = Y \cdot I$$

$$\begin{bmatrix} \mathrm{GCFB} \\ \mathrm{GCFM} \end{bmatrix} = \mathrm{GCF} \quad \cdot \quad \begin{bmatrix} IB \\ IM \end{bmatrix}$$

$$\mathrm{PC} = Y \cdot P$$

$$\begin{bmatrix} \mathrm{TPCDG} \\ \mathrm{TPCNDG} \\ \mathrm{TPCSER} \end{bmatrix} = \mathrm{PC} \quad \cdot \quad \begin{bmatrix} PCDG \\ PCNDG \\ PCSER \end{bmatrix}$$

$$\mathrm{TPCG} = \mathrm{TPCDG} + \mathrm{TPCNDG}$$

- GDP formation by economic sector:

$$(*) \left\{ \begin{array}{l} \mathrm{YAG} = CYAG(1) + CYAG(2) \;\; Y \\ \mathrm{YB} = CYB(1) + CYB(2) \cdot \mathrm{GCFB} \\ \mathrm{YMAN} = CYMAN(1) + CYMAN(2, \cdot \mathrm{GCF} + CYMAN(3) \cdot \mathrm{TPCG} \\ \mathrm{YMIN} = CYMIN(1) + CYMIN(2) \cdot \mathrm{YMAN} \\ \mathrm{YEN} = CYEN(1) + CYEN(2) \cdot Y \\ \mathrm{YSER} = CYSER(1) + CYSER(2) \cdot \mathrm{TPCSER} \\ \mathrm{VAMAN} = CVAMAN(1) + CVAMAN(2) \cdot \mathrm{YMAN} \end{array} \right.$$

- Value added by manufacturing:

$$(**) \left\{ \begin{array}{l} \mathrm{VAMIS} = CVAMIS(1) + CVAMIS(2) \cdot Y \\ \mathrm{VAC} = CVAC(1) + CVAC(2) \cdot \mathrm{TPCNDG} \\ \mathrm{VAM} = CVAM(1) + CVAM(2) \cdot \mathrm{GCFM} + CVAM(3) \cdot \mathrm{TPCDG} \\ \mathrm{VAIG} = CVAIG(1) + CVAIG(2) \cdot \mathrm{YB} + CVAIG(3) \cdot \mathrm{VAM} + \\ \quad + CVAIG(4) \cdot \mathrm{VAC} \end{array} \right.$$

(*) These components have to be normalized with respect to *Y*.
(**) These components have to be normalized with respect to VAMAN.

where

*I* = Investment share in total GDP (fraction)
GCF = Gross fixed capital formation ($10^9$ \$1975)

*IB, IM* = Relative shares of investment spent on construction, and on machinery and equipment, respectively (fractions)

GCFB = Gross fixed capital formation expenditures for construction, and for machinery and equipment, respectively ($10^9\,\$1975$)

*P* = Private consumption share in total GDP (fraction)

PC = Private consumption expenditures ($10^9\,\$1975$)

$\left.\begin{array}{l}PCDG\\ PCNDG\\ PCSER\end{array}\right\}$ = Relative shares of private consumption spent on durable goods, nondurable goods, and services, respectively (fractions)

$\left.\begin{array}{l}TPCDG\\ TPCNDG\\ TPCSER\end{array}\right\}$ = Private consumption expenditures on durable goods, nondurable goods, and services, respectively ($10^9\,\$1975$)

*TPCG* = Private consumption expenditures spent on goods ($10^9\,\$1975$)

For the variables relating to GDP formation, the definitions are given under Variant (1). The prefix "C" is used for the coefficients of the various econometric equations. The dimension of the constant terms in these equations is $10^9\,\$1975$; the other terms are scalars.

The equations do not ensure that the individual components of GDP and of manufacturing value added sum up to the respective totals, so that a subsequent normalization is required. Additivity could not be forced by constrained parameter estimation alone; constraints would also have to be imposed on the structure of GDP formation which is entered exogenously.

### *Energy Demand Calculations by Sector*

#### *(1) Industry*

As mentioned earlier, industrial energy demand is defined here as energy demand for the production of goods. For each economic sector belonging to this group, its value added is used as activity level indicator, or in other words, value added is used as the main driving variable for calculating energy demand of the corresponding industrial subsector. Monetary rather than physical indicators are chosen because of the diversity of goods that are produced. For a detailed energy demand projection, however, the energy intensive group of basic materials industries should be further disaggregated and the energy demand for certain products such as steel, aluminium, cement, glass, paper, fertilizers should be analyzed in physical terms, taking into account substitution possibilities between various production technologies.

The demand calculations for each economic sector in this group are very simple. The basic energy demand of a sector (final energy in the case of specific uses such as motor fuel and electricity, useful energy in the case of thermal uses) is calculated as the product of value added and current energy intensity, which is in turn the product of the base year energy intensity and an exogenously specified index. Useful thermal energy demand of all sectors combined is then converted to final energy demand based on exogenous specification of fuel mix and efficiencies.

Specifically, energy demand of agriculture, construction, and mining is calculated only in final energy terms even for thermal uses, based on the assumption that the decentralized energy use pattern would make the substitution of fossil fuels (mainly oil) by alternative energy sources difficult:

$$\mathrm{MFACM} = \sum_{\mathrm{IS}=1}^{3} \mathit{EIBYR}(\mathit{IS}, 1)\cdot \mathit{EICHG}(\mathit{IS}, 1)\cdot \mathrm{VA}(\mathrm{IS})$$

$$\mathrm{ELSACM} = \sum_{\mathrm{IS}=1}^{3} \mathit{EIBYR}(\mathit{IS}, 2)\cdot \mathit{EICHG}(\mathit{IS}, 2)\cdot \mathrm{VA}(\mathrm{IS})$$

$$\mathrm{FFACM} = \sum_{\mathrm{IS}=1}^{3} \mathit{EIBYR}(\mathit{IS}, 3)\cdot \mathit{EICHG}(\mathit{IS}, 3)\cdot \mathrm{VA}(\mathrm{IS})$$

where

VA(IS) = Value added of sector IS ($10^9\$1975$), with
  IS = 1: Agriculture
  IS = 2: Construction
  IS = 3: Mining
*EIBYR(IS,J)* = Base year energy intensity for energy form J, with
  J = 1: Motor fuel ($10^3$kcal/\$1975)
  J = 2: Electricity (kWhr(e)/\$1975)
  J = 3: Thermal energy ($10^3$kcal/\$1975; final energy)
*EICHG(IS,J)* = Index of energy intensity, i.e., factor of change in energy intensity between the base year and the current model year
MFACM = Total motor fuel use in agriculture/construction/mining (pcal)
ELSACM = Total electricity use in agriculture/construction/mining (TWhr(e))
FFACM = Total thermal energy use in agriculture/construction/mining (pcal)

In the case of manufacturing industries, the demand for motor fuel and for specific uses of electricity (such as lighting, motive power, and electrolysis) is again calculated directly in final energy terms.

For the manufacturing sector, motor fuel and specific electricity demand is calculated in the same way:

$$\mathrm{MFMAN} = \sum_{\mathrm{IS}=4}^{7} \mathit{EIBYR}(\mathit{IS}, 1)\cdot \mathit{EICHG}(4, 1)\cdot \mathrm{VA}(\mathrm{IS})$$

$$\mathrm{ELSMAN} = \sum_{\mathrm{IS}=4}^{7} \mathit{EIBYR}(\mathit{IS}, 2)\cdot \mathit{EICHG}(4, 2)\cdot \mathrm{VA}(\mathrm{IS})$$

where

VA(IS) = Value added of sector IS ($10^9\$1975$), with
  IS = 4: Basic materials
  IS = 5: Machinery and equipment
  IS = 6: Nondurables
  IS = 7: Miscellaneous
*EIBYR(IS,J)* = Base year energy intensity for energy form J, with
  J = 1: Motor fuel ($10^3$kcal/\$1975)
  J = 2: Electricity for specific uses (kWhr(e)/\$1975)
*EICHG(4,J)* = Index of energy intensity (only specified for the manufacturing sector as a whole)
MFMAN = Total motor fuel use in manufacturing (Pcal)
ELSMAN = Total electricity use in manufacturing (TWhr(e))

The demand for thermal energy is first calculated in terms of useful energy and then converted to final energy based on assumptions about the penetration of alternative energy sources in their potential markets and their efficiency relative to the use of electricity with conventional technologies. The potential markets are very broadly defined by three process temperature ranges, namely low-temperature (space heat, hot water, and steam for process temperatures between 80 and 120°C), medium-temperature (steam for process temperatures above 120°C), and high-temperature (furnace/direct heat, excluding iron ore reduction by coke which is accounted for as a specific use). The breakdown of thermal energy demand by type of use, namely space/water heating, steam generation, and furnace/direct heat can either be specified for each manufacturing subsector (in the array *PUSIND*) or for the manufacturing sector as a whole (through the parameters *STSHI* and *STI*). In the first case, electricity penetration rates and fossil fuel efficiencies must be specified for each potential market (namely temperature range) (in *ELPIND(J)*, *EFFIND(J)*, J = 1, 2, 3); in the second case they need to be specified only for the aggregate thermal energy demand (in *ELPIND(4)*, *EFFIND(4)*). The low-temperature share of the steam demand is specified by the parameter *LTH* in both cases.

(a) The breakdown of thermal energy demand by type of use is specified for each manufacturing subsector (i.e., *PUSIND*(. , .) ≠ 0):

- useful energy demand by type of use:

$$\mathrm{USMAN(J)} = \sum_{\mathrm{IS}=4}^{7} \mathit{EIBYR(IS,3)} \cdot \mathit{EICHG(4,3)} \cdot \mathrm{VA(IS)} \cdot \mathit{PUSIND(IS\text{-}3,J)}$$

$$(\mathrm{J} = 1, 2, 3)$$

$$\mathrm{USMAN(4)} = \sum_{\mathrm{J}=1}^{3} \mathrm{USMAN(J)}$$

where

VA(IS) = Value added of sector IS ($10^9$ \$1975)
*EIBYR(IS, 3)* = Base year thermal energy intensity of sector IS ($10^3$ kcal/\$1975)
*EICHG(4, 3)* = Index of thermal energy intensity in manufacturing
*PUSIND(IS-3, J)* = Share of useful thermal energy demand of sector IS for process category J, with
J = 1: Steam generation
J = 2: Furnace/direct heat
J = 3: Space/water heating
USMAN(J) = Useful thermal energy demand in manufacturing for process category J, with
J = 4: Total for all process categories

The penetration of energy sources in the thermal energy market is then determined as follows:

- electricity (conventional):
  PMEL(1) = *ELPIND(1)*·(1 − *HPI*)
  PMEL(2) = *ELPIND(2)*
  PMEL(3) = *ELPIND(3)*·(1 − *HPI*)

- electricity (heat pump):
  $\mathrm{PMHP}(1) = \mathit{HPI} \cdot \mathit{ELPIND}(1)$
  $\mathrm{PMHP}(2) = 0$
  $\mathrm{PMHP}(3) = \mathit{HPI} \cdot \mathit{ELPIND}(3)$
- district heat:
  $\mathrm{PMDH}(1) = \mathit{IDH}$
  $\mathrm{PMDH}(2) = 0$
  $\mathrm{PMDH}(3) = \mathit{IDH}$
- soft solar systems:
  $\mathrm{PMSS}(1) = [\mathit{LTH} \cdot \mathit{SPLT} + (1 - \mathit{LTH}) \cdot \mathit{SPHT}] \cdot \mathit{FIDS}$
  $\mathrm{PMSS}(2) = 0$
  $\mathrm{PMSS}(3) = \mathit{SPLT} \cdot \mathit{FIDS}$
- cogeneration (within industrial plants, as opposed to cogeneration in central power plants)
  $\mathrm{PMCG}(1) = \mathit{LTH} \cdot \mathit{ICOGEN}$
  $\mathrm{PMCG}(2) = 0$
  $\mathrm{PMCG}(3) = \mathit{ICOGEN}$
- fossil fuels (remainder):
  $\mathrm{PMFF}(J) = 1 - [\mathrm{PMEL}(J) + \mathrm{PMHP}(J) + \mathrm{PMDH}(J) + \mathrm{PMSS}(J) + \mathrm{PMCG}(J)]$
  $(J = 1, 2, 3)$
  If PMFF(J) would be negative, the other penetration rates are normalized and PMFF(J) set to zero.
  Finally, PMxx(4) (where xx = EL, HP, DH, SS, CG, FF) and *EFFIND(4)* *are* calculated as weighted averages.

where

*ELPIND(J)* = Share of useful thermal energy demand in manufacturing for process category J (USMAN(J)) that is supplied by electricity (must be specified if *PUSIND* $\neq 0$)
*HPI* = Contribution of heat pumps to low-temperature use of electricity
PMEL(J) = Share of electricity (conventional) in USMAN(J)
PMHP(J) = Share of electricity (heat pump) in USMAN(J)
*IDH* = Share of the manufacturing demand for steam and hot water that is supplied by district heat
PMDH(J) = Share of district heat in USMAN(J)
*LTH* = Share of low-temperature steam in the total steam demand of the manufacturing sector
*SPLT* = Share of the manufacturing demand for low-temperature steam and for hot water which is supplied by solar systems
*SPHT* = Share of the manufacturing demand for high-temperature steam that is supplied by solar systems
*FIDS* = Approximate share of useful thermal energy demand that can be met by a solar installation (i.e., 1-*FIDS* determines the backup requirements)
PMSS(J) = Share of soft solar systems in USMAN(J)
*ICOGEN* = Share of the manufacturing demand for low-temperature steam and hot water which is supplied by fossil fuels, but with cogeneration of electricity

$\mathrm{PMCG(J)}$ = Share of on-site cogeneration in $\mathrm{USMAN(J)}$
$\mathrm{PMFF(J)}$ = Share of fossil fuels in $\mathrm{USMAN(J)}$

(b) The breakdown of thermal energy demand by type of uses is specified only for the manufacturing sector as a whole (i.e., $\mathit{PUSIND}(.\,,.) = 0$):

- useful energy demand by type of use:

$$\mathrm{USMAN(4)} = \sum_{\mathrm{IS}=4}^{7} \mathit{EIBYR(IS,3)} \cdot \mathit{EICHG(4,3)} \cdot \mathrm{VA(IS)}$$

$$\begin{aligned}
\mathrm{USMAN(1)} &= \mathrm{USMAN(4)} \cdot \mathit{STI} \\
\mathrm{USMAN(2)} &= \mathrm{USMAN(4)} \cdot (1 - \mathit{STSHI}) \\
\mathrm{USMAN(3)} &= \mathrm{USMAN(4)} \cdot (\mathit{STSHI} - \mathit{STI})
\end{aligned}$$

where

$\mathit{STSHI}$, $\mathit{STI}$ = Share of useful thermal energy demand in manufacturing for steam generation and space/water heating together ($\mathit{STSHI}$) and for steam generation only ($\mathit{STI}$). (Note: $1 - \mathit{STSHI}$ represents the share of useful energy demand for furnace/direct heat, but excluding the use of coke for iron ore reduction and electrolysis.) The definitions of the other variables are given above under Variant (a).

The penetration of the various energy sources in the thermal energy market in manufacturing is in this case calculated only for the aggregate, not for each temperature range:

$$\begin{aligned}
\mathrm{PMEL(4)} &= \mathit{ELPIND(4)} \cdot (1 - \mathit{STSHI} \cdot \mathit{HPI}) \\
\mathrm{PMHP(4)} &= \mathit{HPI} \cdot \mathit{STSHI} \cdot \mathit{ELPIND(4)} \\
\mathrm{PMDH(4)} &= \mathit{IDH} \cdot \mathit{STSHI} \\
\mathrm{PMSS(4)} &= \{[\mathit{STSHI} - \mathit{STI} \cdot (1 - \mathit{LTH})]\, \mathit{SPLT} + \mathit{STI} \cdot (1 - \mathit{LTH}) \cdot \mathit{SPHT}\}\mathit{FIDS} \\
\mathrm{PMCG(4)} &= [\mathit{STI} \cdot \mathit{LTH} + (\mathit{STSHI} - \mathit{STI})]\, \mathit{ICOGEN} \\
\mathrm{PMFF(4)} &= 1 - [\mathrm{PMEL(4)} + \mathrm{PMHP(4)} + \mathrm{PMDH(4)} + \mathrm{PMSS(4)} + \mathrm{PMCG(4)}]
\end{aligned}$$

If $\mathrm{PMFF(4)}$ would be negative, the other penetration rates are normalized and $\mathrm{PMFF(4)}$ is set to 0.
The definitions of the variables are given above under Variant (a).

Conversion of useful thermal to final energy demand:
[$\mathrm{JL} = 1, \mathrm{JU} = 3$ in Variant (a), $\mathrm{JL} = \mathrm{JU} = 4$ in Variant (b)]

$$\mathrm{DHMAN} = \sum_{\mathrm{J}=\mathrm{JL}}^{\mathrm{JU}} \mathrm{PMDH(J)} \cdot \mathrm{USMAN(J)}$$

$$\mathrm{SOLMAN} = \sum_{\mathrm{J}=\mathrm{JL}}^{\mathrm{JU}} \mathrm{PMSS(J)} \cdot \mathrm{USMAN(J)}$$

$$\mathrm{COGSTH} = \sum_{\mathrm{J}=\mathrm{JL}}^{\mathrm{JU}} \mathrm{PMCG(J)} \cdot \mathrm{USMAN(J)}$$

$$\mathrm{FFMAN} = \left\{ \sum_{J=JL}^{JU} \mathrm{PMFF(J)}\cdot\mathrm{USMAN(J)}/\mathit{EFFIND(J)} \right\} + \mathrm{COGSTH}/\mathit{EFFCOG}$$

$$\mathrm{ELHMAN} = \left\{ \sum_{J=JL}^{JU} [\mathrm{PMEL(J)} + \mathrm{PMHP(J)}/\mathit{EFFHPI}]\cdot\mathrm{USMAN(J)} \right\} - \mathrm{COGSTH/HELRAT}$$

$$\mathrm{COGEL} = \mathrm{COGSTH}/\mathit{HELRAT}$$

where

DHMAN = District heat demand in manufacturing (Pcal)
SOLMAN = Useful energy demand replaced by soft solar systems in manufacturing (Pcal)
COGSTH = Total useful energy demand provided with cogeneration of electricity (low-temperature steam or hot water; Pcal)
*EFFIND(J)* = Average efficiency of fossil fuel use for thermal process J in manufacturing relative to the efficiency of electricity
*EFFCOG* = System efficiency of cogeneration, i.e., (heat + electricity output)/(heat content of fuels used)
FFMAN = Thermal use of fossil fuels in manufacturing (Pcal)
*EFFHPI* = Coefficient of performance of (electric) heat pumps in industry
*HELRAT* = Ratio of heat to electricity in the output of cogeneration systems
ELHMAN = Thermal use of electricity in manufacturing (Pcal) net of byproduct electricity
COGEL = Byproduct electricity from cogeneration in manufacturing (Pcal)

Coke used for pig-iron production currently accounts for the bulk of fossil fuel demand in the iron and steel industry, and in countries with a large steel industry it represents a major item of industrial energy demand. There has been a gradual penetration of electric steel production from scrap (the share in industrialized countries is currently in the range of 10–20 percent of total steel production with some exceptions), but in general steel is produced via the blast furnace route. The coke rate in blast furnaces could be considerably reduced in the past, partly through technological improvements, but to a large extent at the expense of fuel oil and gas injections. With an expected further increase in the relative price of these fuels, such a substitution is not very likely in the future. The alternative route of prereduction of iron ore with natural gas followed by electric smelting seems promising only for countries with indigenous natural gas resources. One can therefore expect that blast furnaces would be only slowly replaced by other technologies, and this is the reason why the alternatives were not explicitly considered.

Specifically, steel production is projected as a function of value added by basic materials industries (which include the iron and steel industry). Coke use for pig-iron production is then calculated based on assumptions about the share of nonelectric steelmaking, the amount of pig-iron required to produce one ton of steel in nonelectric furnaces (which depends on scrap additions), and of the coke rate.

$$\mathrm{PSTEEL} = \mathit{CPST(1)} + \mathit{CPST(2)}\cdot\mathrm{VAIG}$$
$$\mathrm{COKE} = \mathrm{PSTEEL}\cdot\mathit{BOF}\cdot\mathit{IRONST}\cdot(\mathit{EICOK}/1000)\cdot 7$$

where

*CPST(1)* and *CPST(2)* are constants with the dimensions $10^6$ tons and tons/$10^3$ \$value added (VA), respectively
VAIG = Value added of basic materials industries ($10^9$ \$1975)
PSTEEL = Total amount of steel production ($10^6$ tons)
*BOF* = Share of steel produced in nonelectric furnaces
*IRONST* = Tons of pig-iron input per ton of steel produced (the residual is assumed to be scrap)
*EICOK* = Coke input in blast furnaces per unit output of pig-iron
COKE = Coke demand for pig-iron production (Pcal)

Electricity use in the iron and steel industry is accounted for under specific electricity uses of basic materials industries. Thermal energy uses in this industry is also included under the basic materials sector.

The "feedstocks" category should in principle include all uses of energy sources as a raw material; here it applies mainly to certain oil products such as naphtha, lubricants, and bitumen. The demand for these products has been linked in a simplistic form to the value added of basic materials industries (which include the petrochemical industry):

$$\mathrm{FEED} = [\mathit{CFEED(1)} + \mathit{CFEED(2)} \cdot \mathrm{VAIG}] \cdot 10$$

where

*CFEED(1)* and *CFEED(2)* are constants with the dimensions $10^6$ tons and tons/$10^3$ \$VA, respectively
VAIG = Value added of basic materials industries ($10^3$ \$1975)
FEED = Demand for feedstocks (Pcal)

Finally, some aggregates of industrial energy demand (i.e., energy demand for the production of goods) are calculated:

$$\begin{aligned}
&\mathrm{MFIND = MFACM + MFMAN}\\
&\mathrm{ELSIND = ELSACM + ELSMAN}\\
&\mathrm{ELACM = ELSACM \cdot 0.86}\\
&\mathrm{ELMAN = ELSMAN \cdot 0.86 + ELHMAN}\\
&\mathrm{ELIND = ELACM + ELMAN}\\
&\mathrm{FFIND = FFACM + FFMAN}\\
&\mathrm{FINACM = MFACM + ELACM + FFACM}\\
&\mathrm{FINMAN = FFMAN + ELMAN + DHMAN + SOLMAN + COKE + MFMAN + FEED}\\
&\mathrm{FININD = FINACM + FINMAN}
\end{aligned}$$

where

MFIND = Motor fuel demand in industry (Pcal)
ELSIND = Electricity demand for specific uses, industry (TWhr(e))

ELACM = Electricity demand, agriculture/construction/mining (Pcal)
ELMAN = Electricity demand in manufacturing (Pcal)
ELIND = Total electricity demand, industry (Pcal)
FFIND = Thermal use of fossil fuels, industry (Pcal)
FINACM = Final energy demand agriculture/construction/mining (Pcal)
FINMAN = Final energy demand in manufacturing (Pcal)
FININD = Final energy demand, industry (Pcal)

The definitions of the variables on the right-hand side of the equations have been given above.

*(2) Transportation*

Transportation energy demand is calculated directly in final energy terms, because it is mainly demand for motor fuel; only railways and urban mass transit are presently operated with other energy sources (electricity, or in the case of railways also coal), but the total amount if relatively small. The penetration of electric cars in urban traffic will probably not be able to change the heavy dependence on liquid fuels in the near future.

Three broad categories of transportation are considered: freight, passenger, and a miscellaneous category which includes international and military transportation. The latter category is treated very simplistically; energy demand for these purposes is treated as a function of GDP, i.e.

$$\mathrm{TMISMF} = CMISM(1) + CMISMF(2) \cdot Y$$

where

*CMISMF(1)* and *CMISMF(2)* are constants with dimensions Pcal/\$1975 and Mcal/\$1975, respectively
$Y$ = Total GDP ($10^9$ \$1975)
TMISMF = Motor fuel demand for international and military transportation

In the case of domestic freight transportation, the total demand (in terms of ton-kilometers) is treated as a function of the GDP contribution of the goods-producing sectors*:

$$\mathrm{TKFRT} = CTKFRT(1) + CTKFRT(2) \cdot [Y - (\mathrm{YB} - \mathrm{YSER})]$$

where

*CTKFRT(1)* and *CTKFRT(2)* are constants with dimensions $10^9$ tkm/\$1975 and tkm/\$1975, respectively
$Y$ = Total GDP ($10^9$ \$1975)
YB = GDP contribution of the construction sector ($10^9$ \$1975)
YSER = GDP contribution of the service sectors ($10^9$ \$1975)
TKFRT = Demand for domestic freight transportation ($10^9$ tkm)

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*Excluding construction, where transportation services are usually supplied by the firms themselves and motor fuel demand for these purposes can hardly be isolated since it is usually local transportation.

The model split, i.e., the contribution of the various modes of transportation, are exogenously specified:

$$\begin{bmatrix} \mathrm{TKTRUL} \\ \mathrm{TKTRU} \\ \mathrm{TKTRA} \\ \mathrm{TKBA} \\ \mathrm{TKPIP} \end{bmatrix} = \mathrm{TKFRT} \cdot \begin{bmatrix} TRU \cdot TRUL \\ TRU \cdot (1 - TRUL) \\ FTRA \\ BA \\ PIP \end{bmatrix}$$

where

*TRU* = Share of trucks in the total demand for freight transportation
*TRUL* = Share of local truck transportation in the total freight transportation performed by trucks (the residual is assumed to be long-distance hauls)
*FTRA* = Share of rail in the total demand for freight transportation
*FBA* = Share of inland waterways or coastal shipping in the total demand for freight transportation
*FPIP* = Share of pipelines in the total demand for freight transportation
TKxxxx = Freight transportation service by mode xxxx ($10^9$ tkm)

The energy intensities must also be supplied exogenously, except the intensities of electric and steam locomotives, which are linked to the intensity of diesel locomotives by factors of 0.33 and 3.0, respectively. With these specifications, the energy demand of the various modes is calculated as follows:

$\mathrm{TDTRU} = \mathrm{TKTRU} \cdot (DTRU/1000)$
$\mathrm{TDTRUL} = \mathrm{TKTRUL} \cdot (DTRUL/1000)$
$\mathrm{TDTRAF} = (1 - TRAEF - TRASTF) \cdot \mathrm{TKTRA} \cdot (DTRAF/1000)$
$\mathrm{ELTRAF} = TRAEF\ \mathrm{TKTRA} \cdot 0.33 \cdot (DTRAF/860)$
$\mathrm{STCLF} = TRASTF \cdot \mathrm{TKTRA} \cdot 3(DTRAF/1000)$
$\mathrm{TDBA} = \mathrm{TKBA} \cdot (DBA/1000)$
$\mathrm{TDPIP} = \mathrm{TKPIP} \cdot (DPIP/1000)$

where

*DTRU* = Energy intensity of trucks (average or, if $TRUL \neq 0$, long distance)
*DTRUL* = Energy intensity of trucks for short hauls (only relevant if $TRUL \neq 0$)
*DTRAF* = Energy intensity of diesel freight trains
*TRAEF* = Share of electric freight trains in the total freight transportation by rail
*TRASTF* = Share of steam freight trains in the total freight transportation by rail
*DBA* = Energy intensity of inland waterways and coastal shipping (only motor fuel considered)
*DPIP* = Energy intensity of pipelines (only motor fuel considered)
TDxxxx = Energy demand for freight transportation by mode xxxx (Pcal)
ELTRAF = Electricity demand by electric railways (TWhr(e))

Total motor fuel demand for freight transportation is the sum of the following components:

$$\text{TDFT} = \text{TDTRU} + \text{TDTRUL} + \text{TDTRAF} + \text{TDBA} + \text{TDPIP}$$

i.e., truck (long-distance and local), rail (diesel locomotives), barge, and pipeline.*

Two points should be brought to attention at this point: first, the exogenous specification of the modal split independent of the total demand and independent of the product mix can lead to unrealistic results, and second, it is dangerous to look at transportation from the point of view of energy intensity only. Other aspects, such as costs to provide the necessary infrastructure, speed, unit size, etc. are probably still the dominant factors in the choice of mode, despite the significant increase in energy costs.

For passenger transportation, the main indicators are annual travel distance and car ownership. These indicators can be exogenously linked to monetary indicators such as GDP or private consumption per capita, but such relations are not built into the model. A distinction is made between intercity and intracity transportation; the latter category is linked to the population in large cities, where mass transportation is feasible.

Car is assumed to be the preferred mode for intercity passenger travel, and the residual is assigned to public modes:

$$\begin{aligned} \text{PKI} &= PO \cdot (DI/1000) \\ \text{PIC} &= (PO/CO) \cdot DIC \cdot (LFIC/1000) \\ \text{PCT} &= \text{PKI} - \text{PIC} \end{aligned}$$

where

$PO$ = Total population ($10^6$ people)
$DI$ = Average annual intercity travel distance per person (km/p)
PKI = Total intercity travel ($10^9$ pkm)
$CO$ = Ratio of population to number of cars
$DIC$ = Average annual distance driven per car in intercity traffic (km/car)
$LFIC$ = Average load factor of cars in intercity traffic (p/car)
PIC = Passenger-kilometers by car, intercity ($10^9$ pkm)
PCT = Passenger-kilometers by public transportation, intercity ($10^9$ pkm)

The shares of the various modes of public transportation must be exogenously specified:

$$\begin{bmatrix} \text{TPBU} \\ \text{TPTRA} \\ \text{TPLA} \end{bmatrix} = \text{PCT} \cdot \begin{bmatrix} PBU \\ PTRA \\ PLA \end{bmatrix}$$

where

$PBU$ = Share of buses in intercity passenger travel excluding travel by car
$PTRA$ = Share of trains in intercity passenger travel excluding travel by car

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*Since pipelines transport mostly oil and gas, they were considered explicitly only for Region VI; in the other regions, energy use of pipelines is included under transportation losses.

$PLA$ = Share of airplanes in intercity passenger travel excluding travel by car
TPxxx = Passenger kilometers by mode xxx ($10^9$ pkm)

To calculate the energy consumption associated with each mode of transportation, average load factors, and energy intensities are required. These factors are in general specified per vehicle, except for airplanes where energy intensity and capacity utilization are specified per seat-km. For gasoline, an energy content of 8,500 kcal/l is assumed; for diesel, a factor of 9,000 kcal/l is applied. As in the case of freight transportation, the energy intensity of electric and steam locomotives is related to that of diesel locomotives by factors of 0.33 and 3.0, respectively.

$$\mathrm{TGIC} = \mathrm{PIC}\cdot\{[(GIC/100/LFIC)\cdot 8500]/1000\}$$
$$\mathrm{TDBU} = \mathrm{TPBU}\cdot\{[(DBU/100/LFBU)\cdot 9000]/1000\}$$
$$\mathrm{TDTRAP} = [(1 - TRAEP - TRASTP)\cdot\mathrm{TPTRA}]\cdot[(DTRAP/LFTRA)/1000]$$
$$\mathrm{ELTRAP} = (TRAEP\cdot\mathrm{TPTRA})\cdot[(0.33\cdot DTRAP/LFTRA)/860]$$
$$\mathrm{STCLP} = (TRASTP\cdot\mathrm{TPTRA})\cdot[(3\cdot DTRAP/LFTRA)/1000]$$
$$\mathrm{TDPLA} = \mathrm{TPLA}\cdot[(DPLA/LFP)/1000]$$

where

PIC = Passenger-kilometers by car, intercity ($10^9$ pkm)
$GIC$ = Specific gasoline consumption of cars in intercity traffic (l/100km)
$LFIC$ = Average load factor of cars in intercity traffic (p/car)
TGIC = Total gasoline consumption of cars, intercity traffic (Pcal)
TPBU = Passenger-kilometers by bus, intercity ($10^9$ pkm)
$DBU$ = Specific diesel consumption of buses in intercity traffic (l/100km)
$LFBU$ = Average load factor of buses in intercity traffic (p/bus)
TDBU = Total diesel consumption of buses, intercity (Pcal)
TPTRA = Passenger-kilometers by train ($10^9$ pkm)
$TRAEP$ = Share of electric trains in the total intercity travel by train
$TRASTP$ = Share of steam trains in the total intercity travel by train
$DTRAP$ = Energy intensity of diesel passenger trains (kcal/train-km)
$LFTRA$ = Average load factor of passenger trains (p/train)
TDTRAP = Total diesel consumption of railways for passenger transportation (Pcal)
$ELTRAP$ = Total electricity consumption of railways for passenger transportation (TWhr(e))
STCLP = Total coal consumption of railways for passenger transportation (Pcal)
$DPLA$ = Energy intensity of airplanes (kcal/seat-km)
$LFP$ = Average capacity utilization of airplanes (fraction of seats occupied)
TDPLA = Total fuel consumption by airplanes

Total motor fuel consumption for intercity passenger transportation is then:

$$\mathrm{TMFIP} = \mathrm{TGIC} + \mathrm{TDBU} + \mathrm{TDTRAP} + \mathrm{TDPLA}$$

For intercity passenger transportation, total demand is related to the population living in large cities and an average daily distance traveled per person in these areas:

$$\mathrm{POU} = (1 - \mathit{POLC}) \cdot \mathit{PO}$$
$$\mathrm{PKU} = (\mathit{DU} \cdot 365) \cdot (\mathrm{POU}/1000)$$

where

$\mathit{PO}$ = Total population ($10^6$ people)
$\mathit{POLC}$ = Share of population in large cities
POU = Population living in large cities ($10^6$ people)
$\mathit{DU}$ = Average daily travel distance
PKU = Total passenger kilometers, intracity ($10^9$ pkm)

The distribution between travel by car and mass transit must be exogenously specified:

$$\begin{bmatrix} \mathrm{PUC} \\ \mathrm{PUMT} \end{bmatrix} = \mathrm{PKU} \cdot \begin{bmatrix} \mathit{UC} \\ \mathit{UMT} \end{bmatrix}$$

where

$\mathit{UC}$ = Share of cars in the total demand for intracity passenger transportation
$\mathit{UMT}$ = Share of mass transportation systems in the total demand for intracity passenger transportation
Pxxx are the corresponding absolute figures ($10^9$ pkm)

Together with average load factors and energy intensities, and introducing a split between electric and other modes, energy consumption is calculated as follows:

$$\mathrm{TGUC} = [(1 - \mathit{UCE}) \cdot \mathrm{PUC}] \cdot \{[(\mathit{GUC}/100)\mathit{LFUC}] \cdot 8500\}/1000$$
$$\mathrm{TELUC} = (\mathit{UCE} \cdot \mathrm{PUC}) \cdot (\mathit{ELUC}/\mathit{LFUC})$$
$$\mathrm{TDMT} = [(1 - \mathit{UMTE}) \cdot \mathrm{PUMT}] \cdot \{[(\mathit{DMT}/100/\mathit{LFTMB})\ 9000]/1000\}$$
$$\mathrm{TELMT} = (\mathit{UMTE} \cdot \mathrm{PUMT}) \cdot (\mathit{ELMT}/\mathit{LFMTE})$$

where

$\mathit{UCE}$ = Share of electric cars in the total intracity car travel
$\mathit{LFUC}$ = Average load factor of cars in intracity travel
$\mathit{GUC}$ = Specific gasoline consumption of cars in intracity travel
TGUC = Gasoline consumption of cars in intracity traffic (Pcal)
$\mathit{ELUC}$ = Specific electricity consumption (kWhr(e)/vkm) of electric cars (intracity travel)
TELUC = Electricity consumption by electric cars (TWhr(e))
$\mathit{UMTE}$ = Share of electric mass transit in the total intracity mass transportation
$\mathit{DFMTB}$ = Average load factor of nonelectric mass transit systems
$\mathit{DMT}$ = Specific diesel consumption of buses (1/100km)
TDMT = Motor fuel consumption for intracity mass transportation (Pcal)
$\mathit{ELMT}$ = Specific electricity consumption of intracity mass transportation systems
$\mathit{LFMTE}$ = Average load factor of electric mass transit systems

Total energy consumption for intracity transportation is then:

TMFUP = TDMT + TGUC
TELUP = TELMT + TELUC

where

TMFUP = Total motor fuel consumption (Pcal)
TELUP = Total electricity consumption (TWhr(e))

The sector totals are formed from the following components:

TELTR = TELFT + TELIP + TELUP
TMFTR = TDFT + TMFIP + TMFUP + TMSMF
TCLTR = STCLF + STCLP
ELTR = TELTR·0.86
FINTR = ELTR + TMFTR + TCLTR

where

TELTR = Total electricity consumption for transportation (TWhr(e)) with components: freight, passenger/intercity, passenger/intracity
TMFTR = Total motor fuel consumption for transportation (Pcal) with components: freight, passenger/intercity, passenger/intracity, and miscellaneous
TCLTR = Total coal consumption by railways (Pcal)
ELTR = Same as TELTR, but converted to Pcal
FINTR = Total final energy consumption for transportation (Pcal)

In the course of applying MEDEE-2 to the six regions and later in various country studies, various points turned out in the context of travel demand projections, which should be improved. One of these problem areas is the independent projection of travel distance and modal split: the amount which a person can afford to travel depends both on income and time. Modes with higher speed will therefore tend to increase the total demand for travel more than modes with low average speed.* E.g., the rapid increase of travel demand in the last decades would hardly have been possible without the availability of cars to a majority of the population. And although a saturation is in sight for this mode in some industrialized countries a large increase in air travel would be compatible with the time budget of people, if the money budget of the majority of the population were sufficiently increased. The second problem area is the exogenous specification of load factors. It is true that transportation energy demand could be significantly reduced by improving

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*An interesting study of these relationships was made by Y. Zahavi (1977) Equilibrium between travel demand system supply and urban structure. Transport Decisions in an Age of Uncertainty. Proceedings of the Third World Conference on Transport Research, Rotterdam, 26–28 April 1977. The Hague–Boston: Martinus Nijhoff.

the load factors; in reality however the desire for quicker service often counteracts attempts in this direction. This is especially true for mass transportation modes with their typically large unit sizes. Finally, energy consumption is not the only aspect that has to be considered in projecting travel demand. Other and probably still dominant factors are income and desire for convenience, and speed on one hand, and congestion and pollution on the other hand. It is doubtful whether there is enough empirical evidence to formalize the interaction of all these factors in a model.

### *(3) Household/Service Sector*

Energy demand for accommodation of people in the household/service sector is divided into five basic categories in the MEDEE-2 model, namely space heating, water heating, cooking (these three categories are called "thermal uses"), air-conditioning*, and specific electricity uses. In the service subsector, thermal energy uses are treated in aggregate, since space heating is the single most important category (there are of course exceptions such as hospitals, public swimming pools, hotels, and restaurants).

Space heating is treated in some detail, i.e., by distinguishing between existing stock and new construction, and also by distinguishing between single family houses and apartments.

The stock of dwellings is calculated as follows:

- Initialization for the base year:

```
TDEMDW = 0
DWINCR = 0
CONSDW = 0
TPREDW = $DW$
TPSTDW = 0
TDWSH = $TPREDW \cdot DWSH$
```

- Change in later years:

```
$TDEMDW = DW \cdot [1 - (1 - DEMDW)^{(INCR/s)}]$
$DWINCR = PO/CAPH - DW$
DW = DW + DWINCR
CONSDW = TDEMDW + DWINCR
TPREDW = TPREDW − TDEMDW
if $TPREDW < 0$:
    TPSTDW = TPSTDW + TPREDW
    TPREDW = 0
$POSTDW(I) = [NEWDW(I) \cdot CONSDW + POSTDW(I) \cdot TPSTDW] /$
    $(CONSDW + TPSTDW)$
    I = 1, 2, 3
TPSTDW = TPSTDW + CONSDW
$TDWSH = DW \cdot DWSH$
```

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*In this study, air-conditioning is also treated like a specific electricity use, i.e., no other energy source (gas, solar) is considered.

where

TDEMDW = Dwellings demolished between previous and current model year ($10^6$ dwellings)
DWINCR = Net addition of dwellings between previous and current model year ($10^6$ dwellings)
CONSDW = New constructed dwellings between previous and current model year ($10^6$ dwellings)
TPREDW = Stock of pre-1975 dwellings ($10^6$ dwellings)
*DWSH* = Share of dwellings in climatic conditions where space heating is required
TDWSH = Total stock of dwellings in areas where space heating is required ($10^6$ dwellings)
*DEMDW* = Average demolition rate of dwellings during a 5-year period between the previous and current model years (fraction)
INCR = Length of the period between previous and current model year
*PO* = Total population ($10^6$ people)
*CAPH* = Average number of persons per dwelling
DW = Total stock of dwellings ($10^6$ dwellings)
*NEWDW(I)* = Share of dwellings, constructed between the previous and the current model years, which are of type I
    I = 1: single family house with central heating
    I = 2: apartment with central heating
    I = 3: no central heating available
POSTDW(I) = Share of dwellings constructed after the base year which are of type I as defined above (I = 1, 2, 3)

The useful thermal energy demand for space heating is in the case of dwellings constructed before the base year calculated from the average heat loss in the base year after allowing for a reduction of this level due to improved insulation.

$$\mathrm{PRESH(I)} = [\mathit{PREDW(I)}\cdot\mathrm{TPREDW}\cdot\mathit{DWSH}]\cdot\{[\mathit{SHDWO(I)}\cdot(1-\mathit{ISO(I)})]/1000\}$$

where

*PREDW(I)* = Share of dwellings constructed before the base year which are of type I as defined above (I = 1, 2, 3); the distribution can change due to differential demolition rates and due to installation of central heating in existing buildings
TPREDW = Stock of dwellings constructed before the base year ($10^6$ dwellings)
*DWSH* = Share of dwellings in climatic conditions where space heating is required
*SHDWO(I)* = Average heat loss in a dwelling of type I (I = 1, 2, 3) in the base year ($10^3$ kcal/dwelling/yr)
*ISO(I)* = reduction of the average heat loss of dwellings constructed before the base year until the current model year, expressed as a fraction of the average heat loss in the base year (I = 1, 2, 3)
*PRESH(I)* = Useful energy demand for space heating in dwellings of type I (I = 1, 2, 3) which were constructed before the base year

In the case of dwellings constructed after the base year, energy demand for space heating is calculated taking into account the climatic conditions (as expressed by heating degree-days), the average size of dwellings (which tends to increase), and an average heat loss factor (which tends to decrease due to better insulation and heat management practices). The heat loss factor is normalized to the floor area and should include all losses through walls and windows as well as ventilation losses. Free heat gains are taken care of in a crude form by calculating the heating degree-days based on a reference temperature of 18°C and assuming that the difference between this temperature and a standard indoor temperature of 21°C would come from lights, electrical equipment, people, etc.

$$\mathrm{POSTSH(I)} = [\mathrm{POSTDW(I)} \cdot \mathrm{TPSTDW} \cdot \mathit{DWSH}] \cdot \{[(\mathit{DWS(I)} \cdot \mathit{K(I)} \cdot \mathit{DD} \cdot 24)/1000]/1000\}$$

where

$\mathrm{POSTDW(I)}$ = Share of dwellings constructed after the base year which are of type I (I = 1, 2, 3)
$\mathrm{TPSTDW}$ = Stock of dwellings constructed after the base year ($10^6$ dwellings)
$\mathit{DWSH}$ = Share of dwellings in climatic conditions where space heating is required
$\mathit{DWS(I)}$ = Average size of dwellings of type I (I = 1, 2, 3) which have been constructed after the base year ($\mathrm{m}^2$)
$\mathit{K(I)}$ = Average heat loss factor of such dwellings (I = 1, 2, 3) ($\mathrm{kcal/m^2 h ^\circ C}$)
$\mathit{DD}$ = Average number of heating degree-days per year, weighted by the population.*

Total useful energy demand for space heating is then given by:

$$\mathrm{SH} = \sum_{\mathrm{I}=1}^{3} [\mathrm{PRESH(I)} + \mathrm{POSTSH(I)}]$$

Useful energy demand for the other four categories is projected in a very simple way:

- Water heating:
  $\mathrm{HW} = (\mathrm{DW} \cdot \mathit{DWHW}) \cdot [(\mathit{HWCAP} \cdot \mathit{CAPH})/1000]$

where

$\mathrm{DW}$ = Total stock of dwellings ($10^6$ units)
$\mathit{DWHW}$ = Share of dwellings where hot water supply is provided

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*For a particular site, degree-days can be calculated as follows:

$$\mathrm{DD} = \sum_{i:t_i^{\mathrm{ave}} < t_{\mathrm{thresh}}} \left| t_i^{\mathrm{ave}} - t_{\mathrm{ref}} \right|$$

where
$i = 1$ to 365
$t_i^{\mathrm{ave}}$ = Mean temperature of day i
$t_{\mathrm{ref}}$ = Indoor temperature level to be maintained by the heating system (18°C)
$t_{\mathrm{thresh}}$ = Threshold value; a day counts as a heating degree-day only if the mean daily temperature falls below this threshold value – smaller differences are compensated by the storage capacity of the walls. This threshold value varies from 12°C in Scandinavia, 15°C in countries like FRG and Austria, and even 18°C in the USA, reflecting the different building standards in these countries.

$HWCAP$ = Useful energy demand for water heating per person per year ($10^3$ kcal/p/yr)
$CAPH$ = Average number of persons per dwelling
HW = Total useful energy demand for water heating (Pcal)

- Cooking:
  $\mathrm{COOK} = \mathrm{DW} \cdot (COOKDW/1000)$

where

DW = Total stock of dwellings ($10^6$ units)
$COOKDW$ = Useful energy demand for cooking per dwelling per year ($10^3$ kcal/dw/yr)
COOK = Total useful energy demand for cooking (Pcal)

- Air-conditioning:
  $\mathrm{ACH} = (\mathrm{DW} \cdot DWAC) \cdot (ACDW/1000)$

where

DW = Total stock of dwellings ($10^6$ units)
$DWAC$ = Share of dwellings with air-conditioning
$ACDW$ = Specific cooling requirements per dwelling ($10^3$ kcal/dw/yr)
ACH = Total demand for cooling (Pcal)

- Electricity demand for purposes other than space and water heating, cooking and water heating, cooking and air-conditioning:
  $\mathrm{ELAP} = \mathrm{DW} \cdot ELAPDW/1000$

where

DW = Total stock of dwellings ($10^6$ units)
$ELAPDW$ = Average annual electricity consumption per dwelling (kWhr(e))
$ELAP$ = Total electricity consumption of household for "specific uses" (TWhr(e))

In the service sector, energy demand is related to the floor area, which is in turn derived from the GDP contribution and an average floor area per worker. A distinction between old and new buildings is made both for thermal and for specific electricity uses, because of significantly different standards in new buildings. The labor force is calculated as follows:

$$\mathrm{PLSER} = PYSER^{CPLSER}\,*$$
$$\mathrm{LSER} = PO \cdot PLF \cdot PARTLF \cdot \mathrm{PLSER}$$

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*It would be better to calculate the service sector labor force from GDP contribution and relative productivity. At constant prices, the productivity of the service sector tends to increase less than that of industry, so that in recent years in several developed countries the GDP share remained almost constant despite a strong increase in the share of labor force employed in the service sector.

where

*PYSER* = Relative GDP contribution of the service sector (fraction)
*CPLSER* = Constant, to be calculated from the equation: $\mathit{CPLSER} = \ln \mathrm{PLSER} / \ln \mathit{PYSER}$ for the base year (or by regression from a number of years)
PLSER = Service sector share of labor force (fraction)
*PO* = Total population ($10^6$ people)
*PLF* = Potential labor force (share of population in the age group 15–64)
*PARTLF* = Labor force participation (ratio of actual labor force to potential labor force)
LSER = Service sector labor force ($10^6$ workers)

The floor area is calculated in a similar way as the stock of dwellings:

- Initialization for the base year:
  $\mathrm{TDEMAR} = 0$
  $\mathrm{ARINCR} = 0$
  $\mathrm{CONSAR} = 0$
  $\mathrm{AREAO} = \mathit{TAREA}$
  $\mathrm{AREAN} = 0$
  $\mathrm{TARSH} = \mathrm{AREAO} \cdot \mathit{ARSH}$

where

TDEMAR = Service sector floor area demolished between previous and current model year ($10^6\,\mathrm{m}^2$)
ARINCR = Net addition of service sector floor area between previous and current model year ($10^6\,\mathrm{m}^2$)
*TAREA* = Total service sector floor area ($10^6\,\mathrm{m}^2$)
CONSAR = New constructed service sector floor area between previous and current model year ($10^6\,\mathrm{m}^2$)
AREAO = Pre-1975 service sector floor area ($10^6\,\mathrm{m}^2$)
AREAN = Post-1975 service sector floor area ($10^6\,\mathrm{m}^2$)
*ARSH* = Share of floor area in climatic conditions where heating is required
TARSH = Total service sector floor area, where space heating is required ($10^6\,\mathrm{m}^2$)

- Change in later years:
  $\mathrm{TDEMAR} = \mathrm{TAREA} \cdot [1 - (1 - \mathit{DEMAR})^{(\mathrm{INCR}/5)}]$
  $\mathrm{ARINCR} = \mathit{AREAL} \cdot \mathrm{LSER} - \mathrm{TAREA}$
  $\mathrm{TAREA} = \mathrm{TAREA} + \mathrm{ARINCR}$
  $\mathrm{CONSAR} = \mathrm{TDEMAR} + \mathrm{ARINCR}$
  $\mathrm{AREAO} = \mathrm{AREAO} - \mathrm{TDEMAR}$
  if $\mathrm{AREAO} < 0$:
    $\mathrm{AREAN} = \mathrm{AREAN} + \mathrm{AREAO}$
    $\mathrm{AREAO} = 0$
  $\mathrm{TARSH} = \mathrm{TAREA} \cdot \mathit{ARSH}$

where

*DEMAR* = Average demolition rate of the floor area of service sector buildings over a 5-year period between the previous and the current model year

*AREAL* = Average floor area per worker in the service sector. (The definition of the other variables has been given above.)

Energy demand for thermal uses, specific electricity uses and air-conditioning is then calculated in the following way:

- Thermal uses:
  HSERVO = (AREAO·*ARSH*·*AREAH*)·{[*HAREAO*·(1 − *ISOSV*)]/1000}
  HSERVN = (AREAN·*ARSH*·*AREAH*)·(*HAREAN*/1000)
  THSERV = HSERVO + HSERVN

where

AREAO = Floor area in service sector buildings constructed before the base year ($10^6\,m^2$)
*ARSH* = Share of floor area in climatic conditions where space heating is required
AREAH = Share of that area which is actually heated
*HAREAO* = Average annual useful energy demand for thermal uses in the base year ($10^3$ kcal/$m^2$/yr)
*ISOSV* = Reduction of this rate in the current year relative to the base year level (fraction)
HSERVO = Total useful thermal energy demand of old service sector buildings (Pcal)

The definition of variables to calculate the demand for new service sector buildings is similar and therefore omitted. The total thermal energy demand, THSERV (Pcal), is just the sum of the demand in old and new buildings.

- Specific electricity uses:
  ELSVO = AREAO·(*ELARO*/1000)
  ELSVN = AREAN·(*ELARN*/1000)
  ELSV = ELSVO + ELSVN

where

AREAO = Floor area in service sector buildings constructed before the base year ($10^6\,m^2$)
*ELARO* = Average annual electricity consumption for nonthermal uses in such buildings (kWhr(e)/$m^2$/yr)
ELSVO = Specific electricity demand in old service sector buildings (TWhr(e))

The definition of the variables to calculate the demand in new service sector buildings is similar. ELSV(TWhr(e)) is the total service sector electricity demand for specific uses.

- Air-conditioning
  ACSV = (TAREA·*AREAAC*)·(*ACAREA*/1000)

where

TAREA = Total service sector floor area ($10^6\,m^2$)
*AREAAC* = Share of service sector floor area with air-conditioning

*ACAREA* = Average annual cooling demand in service sector buildings ($10^3$ kcal/m$^2$/yr)
ACSV = Total cooling demand of the service sector

*Conversion of useful thermal to final energy demand:* the four thermal/energy demand categories in the household service sector, for which alternative energy sources are considered, are

USHS(1) = SH
USHS(2) = HW
USHS(3) = COOK
USHS(4) = THSERV

i.e., useful thermal energy demand (in Pcal) for

- space heating in households (SH)
- water heating in households (HW)
- cooking in households (COOK)
- all thermal uses in the service sector (THSERV).

It is assumed that a certain amount of noncommercial fuels would be used by households (the service sector is concentrated in urban areas so that noncommercial fuel use would be rather unlikely):

$$\mathrm{FINNCF} = \mathit{BYRNCF}\cdot\mathit{CHGNCF}\cdot 7$$

$$\mathrm{USNCF} = \mathrm{FINNCF}\cdot\mathit{EFFNCF}$$

$$\mathrm{PNCFH} = \mathrm{USNCF}/\left[\sum_{J=1}^{3} \mathrm{USHS}(3)\right]$$

$$\mathrm{PHSNCF}(J) = \mathrm{PNCFH}\ (J = 1, 2, 3)$$

$$\mathrm{PHSNCF}(J) = 0\ (J = 4)$$

where

*BYRNCF* = Amount of noncommercial fuels used in the base year ($10^6$ tce)
*CHGNCF* = Index of the amount used in the current model year relative to the base year level
FINNCF = Amount of noncommercial fuels used in the current model year ($10^6$ tce)
*EFFNCF* = Average end-use efficiency of noncommercial fuels
USNCF = Total useful energy supplied by noncommercial fuels (Pcal)
PNCFH = Share of useful thermal energy demand in households which is supplied by noncommercial fuels
PHSNCF(J) = Share of useful thermal energy demand for category J as defined above (J = 1, . . . , 4) which is supplied by noncommercial fuels

Electricity penetration must be exogenously specified for each category. For space and water heating in households and for thermal uses in the service sector, a certain fraction of this electricity market is assumed to be replaced by heat pumps. (Other energy sources for heat pumps, such as gas or solar energy, are not considered.)

- Electricity (conventional):
  $\mathrm{PHSEL}(1) = \mathit{ELPHS}(1)\cdot(1-\mathit{HPHS})$
  $\mathrm{PHSEL}(2) = \mathit{ELPHS}(2)\cdot(1-\mathit{HPHS})$
  $\mathrm{PHSEL}(3) = \mathit{ELPHS}(3)$
  $\mathrm{PHSEL}(4) = \mathit{ELPHS}(4)\cdot(1-\mathit{HPHS})$
- Electricity (heat pump):
  $\mathrm{PHSHP}(1) = \mathit{HPHS}\cdot\mathit{ELPHS}(1)$
  $\mathrm{PHSHP}(2) = \mathit{HPHS}\cdot\mathit{ELPHS}(2)$
  $\mathrm{PHSHP}(3) = 0$
  $\mathrm{PHSHP}(4) = \mathit{HPHS}\cdot\mathit{ELPHS}(4)$

where

*ELPHS*(J) = Electricity penetration into thermal energy demand category J (as defined above)
*HPHS* = Average contribution of heat pump to electric space and water heating in the household/service sector
PHSEL(J) = Share of thermal energy demand for category J [USHS(J), as defined above] supplied by resistive use of electricity
PHSHP(J) = Share of USHS(J) supplied by heat pumps.

For space and water heating in the household/service sector, district heat is also considered as a possible energy source, but only in large cities:

$\mathrm{PHSDH}(J) = (1-\mathit{POLC})\cdot\mathit{DHPH}\quad(J = 1, 2, 4)$
$\mathrm{PHSDH}(J) = 0\quad(J = 3)$

where

*POLC* = Share of population living outside large cities
*DHPH* = District heat penetration into space and water heating of dwellings and thermal uses in the service sector (large cities only)
PHSDH(J) = Share of USHS(J) supplied by district heat

Soft solar systems are assumed to be potentially used for space heating in single-family houses with central heating which are constructed after the base year and for water heating. In the service sector, their use is assumed to be restricted to low-rise buildings constructed after the base year.

- Soft solar systems:
  $\mathrm{PHSSS}(1) = \mathrm{POSTSH}(1)\cdot\mathit{FDSHS}\cdot\mathit{SPSH}/\mathrm{USHS}(1)$
  $\mathrm{PHSSS}(2) = \mathit{SPHW}\cdot\mathit{FDHWS}$
  $\mathrm{PHSSS}(3) = 0$
  $\mathrm{PHSSS}(4) = \mathit{PLB}\cdot\mathrm{HSERVN}\cdot\mathit{FDHS}\cdot\mathit{SPSV}/\mathrm{USHS}(4)$

where

POSTSH(1) = Total energy demand for space heating in single-family houses with central heating constructed after the base year (Pcal)

USHS(1) = Total energy demand for space heating in households (Pcal)
*SPSH* = Solar penetration into space heating in post-1975 single-family houses with central heating
*FDSHS* = Approximate share of space heat demand in households that can be met by a solar installation (the residual must be covered by a backup system)
*SPHW* = Solar penetration into water heating in dwellings (total demand)
*FDHWS* = Approximate share of the hot water demand that can be met by a solar installation (the residual must be covered by a backup system)
HSERVN = Total heat demand in service sector buildings constructed after the base year (Pcal)
USHS(4) = Total heat demand in service sector buildings (Pcal)
*PLB* = Share of low-rise buildings (e.g., up to 3 floors) in the total service sector floor area
*SPSV* = Solar penetration into thermal uses in post-1975 low-rise buildings of the service sector
*FDHS* = Approximate share of thermal energy demand in the service sector that can be met by a solar installation (the residual must be covered by a backup system)
PHSSS(J) = Share of USHW(J) (as defined above) which is effectively replaced by solar energy systems

The shares of USHS(J) which are not supplied by one of the energy sources mentioned above must be supplied by commercial fossil fuels, i.e.:

$$\mathrm{PHSFF(J)} = 1 - (\mathrm{PHSNCF(J)} + \mathrm{PHSEL(J)} + \mathrm{PHSHP(J)} + \mathrm{PHSDH(J)} + \mathrm{PHSSS(J)}) \quad (\mathrm{J} = 1, 2, 3, 4)$$

If PMFF(J) would be negative, the other penetration rates are normalized and PMFF(J) set to zero.

The final energy demand of the household/service sector can now be calculated as follows:

- Thermal uses:

$$\mathrm{ELHHS} = \sum_{\mathrm{J}=1}^{4} \mathrm{USHS(J)} \cdot [\mathrm{PHSEL(J)} + \mathrm{PHSHP(J)}/\mathit{EFFHPR}]$$

$$\mathrm{DHHS} = \sum_{\mathrm{J}=1}^{4} \mathrm{USHS(J)} \cdot \mathrm{PHSDH(J)}$$

$$\mathrm{SOLHS} = \sum_{\mathrm{J}=1}^{4} \mathrm{USHS(J)} \cdot \mathrm{PHSSS(J)}$$

$$\mathrm{FFHS} = \sum_{\mathrm{J}=1}^{4} \mathrm{USHS(J)} \cdot [\mathrm{PHSFF(J)}/\mathit{EFFHS(J)}]$$

where

*EFFHPR* = Coefficient of performance of (electric) heat pumps in the household/service sector

*EFFHS*(J) = Efficiency of fossil fuel use relative to that of electricity use for thermal energy use category J (J = 1, 2, 3, 4) in the household/service sector.
(The definitions of USHS(J) and PHSxx(J) for xx = EL, HP, DH, SS, FF have been given above.)
ELHHS = Electricity consumption for thermal uses in the household/service sector (Pcal)
DHHS = District heat consumption in the household/service sector (Pcal)
SOLHS = Useful energy demand replaced by soft solar systems in the household/service sector (Pcal)
FFHS = Commercial fossil fuel consumption in the household/service sector (Pcal)

- Specific uses of electricity:
  ELSPHS = ELAP + ELSV

where

ELAP = Specific uses by households (TWhr(e))
ELSV = Specific uses in the service sector (TWhr(e))
ELSPHS = Total specific uses of electricity in the household/service sector (TWhr(e))

- Electricity for air-conditioning:
  USCOOL = ACH + ACSV
  ELAC = USCOOL/*EFFAC*

where

ACH = Total cooling demand of households (Pcal)
ACSV = Total cooling demand of the service sector (Pcal)
USCOOL = Total cooling demand of the household/service sector (Pcal)
*EFFAC* = Coefficient of performance of (electric) air-conditioners
ELAC = Total electricity use for air-conditioning in the household/service sector

- Sector totals are given by:
  ELHS = ELAC + ELHHS + ELSPHS·0.86
  FINHS = FFHS + ELHS + DHHS + SOLHS
  FHSPNC = FINHS + FINNCF

where

ELHS = Total electricity consumption of the household/service sector (Pcal) (air-conditioning + specific + thermal uses)
FINHS = Commercial final energy demand of the household/service sector (Pcal)
FHSPNC = Commercial plus noncommercial final energy demand of the household/service sector (Pcal)

The main problem in projecting energy demand for the household/service sector along the framework presented above seems to be the lack of relations indicating whether the costs to build an infrastructure as assumed in a scenario are plausible within the macroeconomic background, since these costs in general still dominate energy costs. Such problem areas are for instance housing construction, construction of electricity networks (in developing countries) and of district heating systems, purchase of household equipment, etc. Another shortcoming is the superficial treatment of air-conditioning, the demand for which should also be linked to the particular climatic conditions, like the demand for space heating. The definition of the potential markets for the various energy sources is rough, but has turned out helpful. A problem area is, however, the independent calculation of total demand for, say, space heating and of the market shares of various energy sources. Electric heating, for example, can only be installed if the insulation level meets certain standards which are stricter than for other energy sources; demand for space and water heating in apartments with district heat connection tends to be higher than in other dwellings; installation of solar systems may not give the expected savings if at the same time the comfort level increases, etc. Despite these problems, the framework was helpful for the broad assessment required in this global study.

Total final energy demand is calculated in MEDEE-2 for the following energy sources/categories (unit: Pcal):

FF = FFHS + FFIND
DH = DHHS + DHIND
SOL = SOLHS + SOLIND
ELEC = ELTR + ELHS + ELIND
TMF = TMFTR + MFIND
COALSP = TCLTR + COKE
ENERGY = FF + DH + SOL + ELEC + TMF + COALSP + FEED
ENPNCF = ENERGY + FINNCF

where

FF = Total thermal use of fossil fuels (household/service, industry)
DH = Total district heat demand (household/service, industry)
SOL = Total solar energy demand (household/service, industry)
ELEC = Total electricity demand (transportation, household/service, industry)
TMF = Total motor fuel demand (transportation, industry)
COALSP = Specific uses of coal (transportation, industry)
ENERGY = Total commercial final energy demand (including feedstocks)
ENPNCF = Total commercial plus noncommercial final energy demand

In this study, only oil products were considered for motor fuels and feedstocks, although in the long run they could be substituted by other sources. For the thermal use of fossil fuels, coal, oil, and gas were considered in all regions; in developing regions, charcoal and biogas were also considered as alternatives, although their use would be more restricted. Charcoal is also treated as a substitute for coke in pig-iron production. These fuel allocations together with assumptions about transportation/distribution losses and internal consumption by energy producing industries is a necessary step to convert the MEDEE-2 output into the input suitable for the supply model MESSAGE, i.e., into secondary energy demand. The assumptions entering in this intermediate step are described in Part IV of *Energy in a Finite World – A Global Systems Analysis* by the Energy Systems Program Group (1981). Attempts are currently being made by the Energy Systems Program of IIASA to formalize this step and to treat energy end-use also in an optimization framework.

## APPENDIX B2: DEFINITION OF PARAMETER VARIABLES*

| *Variable* | *Unit* | *Explanation* |
|---|---|---|
| *PO* | $10^6$ | Total population |
| *PLF* | fraction | Share of population of age 15–64 in the total population (potential labor force) |
| *PARTLF* | fraction | Share of potential labor force actually working |
| *POLC* | fraction | Share of population living outside large cities (the definition in terms of city size varies from region to region; the variable is used to determine the approximate potential market for district heating and mass transportation systems) |
| *PRUR* | fraction | Share of rural population (according to UN definition), the variable was not used in the present version of MEDEE-2, but was considered outside the model for estimating some other parameters |
| *CAPH* | persons per household | Average household size (the number of dwellings is calculated as *PO/CAPH*, i.e., the term household is used in the sense "persons living together in one dwelling") |
| *Y* | $10^9\,\$1975$ | Total GDP |
| **Group (a):** | | |
| *PYAG[YREL(1)]*<br>*PYB[YREL(2)]*<br>*PYMIN[YREL(3)]*<br>*PYMAN[YREL(4)]*<br>*PYEN[YREL(5)]*<br>*PYSER[YREL(6)]* | | Distribution of GDP formation by kind of economic activity. Sectors considered: agriculture, construction, mining, manufacturing, energy, services |
| *PVAIG[VAREL(1)]*<br>*PVAM[VAREL(2)]*<br>*PVAC[VAREL(3)]*<br>*PVAMIS[VAREL(4)]* | | Distribution of manufacturing value added. Sectors considered: basic materials, machinery and equipment, nondurables, and miscellaneous industries |
| **Group (b):** | | |
| *I*<br>*(IB)*<br>*(IM)* | | Share of GDP spent on investments (*I*), and distribution of investments among construction (*IB*), and machinery and equipment (*IM*) |
| *P*<br>*(PCDG)*<br>*(PCNDG)*<br>*(PCSER)* | | Share of private consumption expenditures in total GDP (*P*), and distribution of private consumption among durable goods (*PCDG*), nondurable goods (*PCNDG*), and services (*PCSER*) |

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*Constants and initial values are marked by $^c$ and $^i$, respectively; the values of all other variables have to be specified for each point in time considered. The names correspond in general to those used in the MEDEE-2 code; if not, the name used in the program is shown in brackets.

| *Variable* | *Unit* | *Explanation* |
|---|---|---|
| **Group (c):** | | |
| $CYAG^c$(1 to 2) | | Coefficients of linear equations to determine the GDP formation of 6 major economic sectors, the value added by manufacturing, and the value added contributions of 4 aggregated manufacturing sectors as a function of total GDP and the structure of GDP expenditure; the parameters in group (b) and (c) need only be specified if the parameters in group (a) are not specified. |
| $CYB^c$(1 to 2) | | |
| $CYMIN^c$(1 to 2) | | |
| $CYMAN^c$(1 to 3) | | |
| $CYEN^c$(1 to 2) | | |
| $CYSER^c$(1 to 2) | | |
| $CVAMAN^c$(1 to 2) | | |
| $CVAIG^c$(1 to 4) | | |
| $CVAM^c$(1 to 3) | | |
| $CVAC^c$(1 to 2) | | |
| $CVAMIS^c$(1 to 2) | | |
| *EI.AGR.MF.*$^i$*[EIBYR(1, 1)]* | $10^3$ kcal/$VA (for MF, TH); kWhr(e)/$VA (for EL) | Specific energy consumption per dollar value added by sector and energy form in the base year.<br>Sectors: AGR = agriculture, CON = construction, MIN = mining.<br>Energy forms: MF = motor fuel, EL = electricity, TH = thermal uses (final energy). |
| *EI.AGR.EL*$^i$*[EIBYR(1, 2)]* | | |
| *EI.AGR.TH.*$^i$*[EIBYR(1, 3)]* | | |
| *EI.CON.MF*$^i$*[EIBYR(2, 1)]* | | |
| *EI.CON.EL*$^i$*[EIBYR(2, 2)]* | | |
| *EI.CON.TH*$^i$*[EIBYR(2, 3)]* | | |
| *EI.MIN.MF*$^i$*[EIBYR(3, 1)]* | | |
| *EI.MIN.EL*$^i$*[EIBYR(3, 2)]* | | |
| *EI.MIN.TH*$^i$*[EIBYR(3, 3)]* | | |
| *EI.BM.MF*$^i$*[EIBYR(4, 1)]* | $10^3$ kcal/$VA (for MF, US); kWhr(e)/$VA (for EL) | Specific energy consumption per dollar value added by manufacturing subsector and energy form in the base year.<br>Sectors: BM = basic materials, ME = machinery and equipment, *ND* = nondurables, MS = miscellaneous industries.<br>Energy forms: MF = motor fuel, EL = electricity, US = thermal uses (useful energy). |
| *EI.BM.EL*$^i$*[EIBYR(4, 2)]* | | |
| *EI.BM.US*$^i$*[EIBYR(4, 3)]* | | |
| *EI.ME.MF*$^i$*[EIBYR(5, 1)]* | | |
| *EI.ME.EL*$^i$*[EIBYR(5, 2)]* | | |
| *EI.ME.US*$^i$*[EIBYR(5, 3)]* | | |
| *EI.ND.MF*$^i$*[EIBYR(6, 1)]* | | |
| *EI.ND.EL*$^i$*[EIBYR(6, 2)]* | | |
| *EI.ND.US*$^i$*[EIBYR(6, 3)]* | | |
| *EI.MS.MF*$^i$*[EIBYR(7, 1)]* | | |
| *EI.MS.EL*$^i$*[EIBYR(7, 2)]* | | |
| *EI.MS.US*$^i$*[EIBYR(7, 3)]* | | |
| *CH.AGR.MF[EICHG(1, 1)]* | | Ratio of energy intensity in the current year relative to the base year by sector and by energy forms (same sectors and energy forms as above) |
| *CH.AGR.EL[EICHG(1, 2)]* | | |
| *CH.AGR.TH[EICHG(1, 3)]* | | |
| *CH.CON.MF[EICHG(2, 1)]* | | |
| *CH.CON.EL[EICHG(2, 2)]* | | |
| *CH.CON.TH[EICHG(2, 3)]* | | |
| *CH.MIN.MF[EICHG(3, 1)]* | | |
| *CH.MIN.EL[EICHG(3, 2)]* | | |
| *CH.MIN.TH[EICHG(3, 3)]* | | |
| *CH.MAN.MF[EICHG(4, 1)]* | | Ratio of energy intensity in the current year relative to the base year in the |
| *CH.MAN.EL[EICHG(4, 2)]* | | |

| *Variable* | *Unit* | *Explanation* |
|---|---|---|
| | | manufacturing sector, by energy form (same energy forms as above; the same factor is applied to all manufacturing subsectors). |
| *PUSIND*[c]*(I, J)* | fractions | Share of useful thermal energy demand of manufacturing sector I for process category J |
| **Sectors:** | | |
| I = 1 | | Basic materials |
| I = 2 | | Machinery and equipment |
| I = 3 | | Nondurables |
| I = 4 | | Miscellaneous manufacturing industries |
| **Process Categories:** | | |
| J = 1 | | Steam generation |
| J = 2 | | Furnace/direct heat |
| J = 3 | | Space/water heating |
| *STSHI*<br>*STI* | fractions | Share of useful thermal energy demand in manufacturing for steam generation and space/water heating together (*STSHI*) and for steam generation only (*STI*). (Note: 1 − *STSHI* represent the share of useful energy demand for furnace/direct heat, but excluding the use of coke for iron ore reduction and electrolysis.) These two variables must be specified only if the array *PUSIND* is zero. |
| *LTH* | fraction (relative to *STI*) | Share of low-temperature steam in the total steam demand of the manufacturing sector. |
| *ELPIND(J)* | fraction | Share of useful thermal energy demand in manuffacturing for process category J (J = 1, 2, 3) that is supplied by electricity (must be specified if *PUSIND* ≠ 0) |
| *ELPIND(4)* | fraction | Average electricity penetration into thermal uses in manufacturing (must be specified only if *PUSIND* = 0) |
| *(HPI)* | fraction | Contribution of heat pumps to low-temperature use of electricity |
| *EFFHPI* | thermal energy extracted/electric energy input | Coefficient of performance of (electric) heat pumps in industry |
| *IDH* | fraction | Share of the manufacturing demand for steam and hot water that is supplied by district heat |
| *SPLT* | fraction | Share of the manufacturing demand for low-temperature steam and for hot water which is supplied by solar systems |
| *SPHT* | fraction | Share of the manufacturing demand for high-temperature steam that is supplied by solar systems |

| *Variable* | *Unit* | *Explanation* |
|---|---|---|
| *FIDS* | fraction | Approximate share of useful thermal energy demand that can be met by a solar installation (i.e., 1 − *FIDS* determines the backup requirements) |
| *ICOGEN* | fraction | Share of the manufacturing demand for low-temperature steam and hot water which is supplied by fossil fuels, but with cogeneration of electricity |
| *EFFCOG* | fraction | System efficiency of cogeneration, i.e., (heat + electricity output)/(heat content of fuels used) |
| *HELRAT* | kWhr(e) steam/ kWhr(e) electricity | Ratio of heat to electricity in the output of cogeneration systems |
| *EFFIND(J)* | fraction | Average efficiency of fossil fuel use for thermal process J (J = 1, 2, 3) in manufacturing relative to the efficiency of electricity (must be specified if *PUSIND* $\neq 0$) |
| *EFFIND(4)* | fraction | Average efficiency of fossil fuel use in thermal processes relative to the efficiency of electricity (must be specified only if *PUSIND* $= 0$) |
| *CFEED(1)*$^c$ | $10^6$ tons | Constants used to project the feedstock requirements of the petrochemical industry |
| *CFEED(2)*$^c$ | tons/$10^3$ \$VA | |
| *CPST(1)*$^c$ | $10^6$ tons | Constants used to project the amount of steel produced |
| *CPST(2)*$^c$ | tons/$10^3$ \$VA | |
| *BOF* | fraction | Share of steel produced in nonelectric furnaces (the electricity requirements for electric steelmaking must be reflected in *EI.BM.EL* for the base year, and in *CH.MAN.EL* for the projections) |
| *IRONST* | tons of pig-iron/ ton of steel | Tons of pig-iron input per ton of steel produced (the residual is assumed to be scrap) |
| *EICOK* | kg coke/ton of pig-iron | Coke input in blast furnaces per unit output of pig-iron |
| *CTKFRT(1)* | $10^9$ ton-km | Constants used to project the total demand for freight transportation |
| *CTKFRT(2)* | ton-km/\$1975 | |
| *CMISMF(1)* | $10^{12}$ kcal | Constants used to project the total motor fuel demand for international, military, and miscellaneous transportation |
| *CMISMF(2)* | $10^3$ kcal/\$1975 | |
| *TRU* | fraction | Share of trucks in the total demand for freight transportation |
| *(TRUL)* | fraction (relative to *TRU*) | Share of local truck transportation in the total freight transportation performed by trucks (the residual is assumed to be long-distance hauls) |
| *FTRA* | fraction | Share of rail in the total demand for freight transportation |
| *(TRAEF)* | fraction (relative to *FTRA*) | Share of electric freight trains in the total freight transportation by rail |

| *Variable* | *Unit* | *Explanation* |
|---|---|---|
| *(TRASTF)* | fraction (relative to *FRTRA*) | Share of steam freight trains in the total freight transportation by rail |
| *BA* | fraction | Share of inland waterways or coastal shipping in the total demand for freight transportation |
| *PIP* | fraction | Share of pipelines in the total demand for freight transportation |
| *DTRU* | kcal/ton-km | Energy intensity of trucks (average or, if $TRUL \neq 0$, long-distance) |
| *DTRUL* | kcal/ton-km | Energy intensity of trucks for short hauls (only relevant if $TRUL \neq 0$) |
| *DTRAF* | kcal/ton-km | Energy intensity of diesel freight trains |
| *(STDTRA)* | factor | Ratio between the energy intensities of steam and diesel trains |
| *(ELDTRA)* | factor | Ratio between the energy intensities of electric and diesel trains |
| *DBA* | kcal/ton-km | Energy intensity of inland waterways and coastal shipping (only motor fuel considered) |
| *DPIP* | kcal/ton-km | Energy intensity of pipelines (only motor fuel considered) |
| *DI* | km/yr/person | Average intercity distance traveled per year per person (applies to the total population) |
| *DU* | km/day/person | Average intracity distance traveled per day per person (applies only to the population living in large cities) |
| *CO* | population/ number of cars | Inverse of car ownership |
| *DIC* | km/yr/car | Average intercity distance driven per year per car (one must be careful that the average distance driven in intracity travel as implied by the assumptions on *PO, POLC, DU, UC, LFUC* together with the assumption on *DIC*, matches the total average distance driven per year per car) |
| *LFIC* | persons per car | Average load factor of cars in intercity travel |
| *UC* | fraction | Share of cars in the total demand for intracity passenger transportation |
| *(UCE)* | fraction (relative to *UC*) | Share of electric cars in the total intracity car travel |
| *LFUC* | persons per car | Average load factor of cars in intracity travel |
| *PBU* | fraction | Share of buses in intercity passenger travel excluding travel by car |
| *PTRA* | fraction | Share of trains in intercity passenger travel excluding travel by car |
| *(TRAEP)* | fraction (relative to *PTRA*) | Share of electric trains in the total intercity travel by train |

| *Variable* | *Unit* | *Explanation* |
|---|---|---|
| *(TRASTP)* | fraction (relative to *PTRA*) | Share of steam trains in the total intercity travel by train |
| *PLA* | fraction | Share of airplanes in intercity passenger excluding travel by car |
| *LFBU* | persons per bus | Average load factor of buses (intercity) |
| *LFTRA* | persons per train | Average load factor of trains (intercity) |
| *LFP* | fraction | Average capacity utilization factor of airplanes |
| *UMT* | fraction | Share of mass transportation systems in the total demand for intracity passenger transportation |
| *(UMTE)* | fraction (relative to *UMT*) | Share of electric mass transit in the total intracity mass transportation ($1 - UMTE$ is the share of buses) |
| *LFMTB* | persons per bus | Average load factor of nonelectric mass transit systems (intracity) |
| *LFMTE* | persons per vehicle | Average load factor of electric mass transit systems (intracity) |
| *GIC* | liter/100 veh-km | Specific gasoline consumption of cars in intercity travel |
| *GUC* | liter/100 veh-km | Specific gasoline consumption of cars in intracity travel |
| *ELUC* | kWhr(e)/veh-km | Specific electricity consumption of electric cars (intracity travel) |
| *DBU* | liter/100 veh-km | Specific diesel consumption of buses (intercity) |
| *DTRAP* | kcal/train-km | Specific fuel consumption of diesel passenger trains (intercity) |
| *DPLA* | kcal/seat-km | Specific energy consumption of airplanes |
| *DMT* | liter/100 veh-km | Specific diesel consumption of buses (intracity) |
| *ELMT* | kWhr(e)/veh-km | Specific electricity consumption of intracity mass transportation systems |
| $DD^c$ | degree-day | The definition in the US Statistical Abstract (see US (1976a), p. 178) is as follows: "A unit, based upon temperature difference and time, used in estimating fuel consumption and specifying nominal heating load in winter. For any one day, when the mean temperature is less than 65°F there exist as many degree days as there are Fahrenheit degrees difference in the temperature between the average temperature for the day and 65°F." The definition used here differs in that it is (i) based on degrees Celsius, with the threshold being 18°C; (ii) based on monthly average temperature; (iii) averaged over a region (weighted by population) by selection of a few representative cities. Our values are therefore rough approximations. |
| $DWSH^c$<br>$ARSH^c$ | fractions | Share of dwellings (service sector floor area) which is in climatic conditions where heating is required |

| *Variable* | *Unit* | *Explanation* |
|---|---|---|
| $DW\text{-}75^{i}(DW)$ | $10^6$ dwellings | Total stock of dwellings in the base year |
| $SHDWO(1)^{i}$<br>$SHDWO(2)^{i}$<br>$SHDWO(3)^{i}$ | $10^3$ kcal/yr/ dwelling | Specific space heat requirements of pre-75 dwellings (useful energy); 1 = single family house with central heating; 2 = apartment with central heating; 3 = dwelling with room heating only |
| $TAREA\text{-}75^{i}$ $[TAREA]$ | $10^6\,m^2$ | Total floor area of service sector buildings in the base year |
| $CPLSER^{c}$ | | Constant to calculate service sector labor force from the GDP-share of the service sector |
| $HAREAO^{i}$ | $10^3$ kcal/yr/m$^2$ | Specific heat requirements of pre-1975 service sector buildings (useful energy) |
| $BYRNCF^{i}$ | $10^6$ tce | Amount of noncommercial fuels used in the base year; noncommercial fuel use is considered only in the household sector in the model |
| *COOKDW* | $10^3$ kcal/yr/dw | Specific energy consumption for cooking in dwellings (useful energy) |
| *DWHW* | fraction | Share of dwellings with hot water facilities |
| *HWCAP* | $10^3$ kcal/yr/ person | Specific energy consumption for water heating per person (useful energy) |
| *DWAC* | fraction | Share of dwellings with air-conditioning |
| *ACDW* | $10^3$ kcal/yr/dw | Specific cooling requirements per dwelling |
| *ELAPDW* | kWhr(e)/yr/dw | Specific electricity consumption per dwelling (for uses other than space heating, water heating, cooking and air-conditioning) |
| *PREDW(1)*<br>*PREDW(2)*<br>*PREDW(3)* | fractions | Distribution of pre-1975 dwellings per type (definition of dwelling types as for *SHDWO* above) |
| *AREAH* | fraction | Share of service sector floor area (in cold climates) actually heated |
| *ELARO* | kWhr(e)/yr/m$^2$ | Specific electricity consumption in pre-1975 service sector buildings |
| *AREAAC* | fraction | Share of air-conditioned service sector floor area |
| *ACAREA* | $10^3$ kcal/yr/m$^2$ | Specific cooling requirements in the service sector |
| *EFFAC* | thermal energy extracted/electric energy input | Coefficient of performance of (electric) air-conditioners |
| *DEMDW* | fraction | Average demolition rate of dwellings over a 5-year period between the previous and the current model years |
| *NEWDW(1)*<br>*NEWDW(2)*<br>*NEWDW(3)* | fractions | Distribution of dwellings, constructed between the previous and the current model years by type (definition of dwelling types as for *SHDWO* above) |
| *DWS(1)*<br>*DWS(2)*<br>*DWS(3)* | m$^2$/dw | Average floor area heated in post-1975 dwellings (definition of dwelling types as for *SHDWO* above) |

| *Variable* | *Unit* | *Explanation* |
|---|---|---|
| *K(1)*<br>*K(2)*<br>*K(3)* | kcal/hr/$m^2$/°C | Specific heat loss rate in dwellings built after 1975 (definition of dwelling types as for *SHDWO* above) |
| *ISO(1)*<br>*ISO(2)*<br>*ISO(3)* | fractions | Reduction of the average space heat demand of pre-1975 dwellings in the current year relative to that in the base year due to better insulation (definition of dwelling types as for *SHDWO* above) |
| *AREAL* | $m^2$/worker | Average floor area per worker in the service sector |
| *DEMAR* | fraction | Average demolition rate of the floor area of service sector buildings over a 5-year period between the previous and the current model year |
| *HAREAN* | $10^3$ kcal/yr/$m^2$ | Specific heat requirements of post-1975 service sector buildings |
| *ELARN* | kWhr(e)/yr/$m^2$ | Specific electricity consumption in post-1975 service sector buildings |
| *ISOSV* | fraction | Reduction of the average heat demand in pre-1975 service sector buildings in the current year relative to that in the base year due to better insulation |
| *ELP.H.SH[ELPHS(1)]*<br>*ELP.H.HW[ELPHS(2)]*<br>*ELP.H.CK[ELPHS(3)]*<br>*ELP.S.TH[ELPHS(4)]* | fractions | Electricity penetration into thermal uses in the household/service sector. The categories are: *H.SH* = space heating (households); *H.HW* = water heating (households); *H.CK* = cooking (households); *S.TH* = thermal uses (service sector) |
| *(HPHS)* | fraction | Contribution of heat pump to electric space and water heating in the household/service sector |
| *EFFHPR* | thermal energy extracted/electric energy input | Coefficient of performance of (electric) heat pumps in the household/service sector |
| *DHPH* | fraction | District heat penetration into space and water heating of dwellings and thermal uses in the service sector (large cities only) |
| *SPSH* | fraction | Solar penetration into space heating in post-1975 single family houses with central heating |
| *FDSHS* | fraction | Approximate share of space heat demand in households that can be met by a solar installation (the residual must be covered by a backup system) |

| *Variable* | *Unit* | *Explanation* |
|---|---|---|
| *SPHW* | fraction | Solar penetration into water heating in dwellings (total demand) |
| *FDHWS* | fraction | Approximate share of the hot water demand that can be met by a solar installation (the residual must be covered by a backup system) |
| *PLB* | fraction | Share of low-rise buildings (e.g., up to 3 floors) in the total service sector floor area |
| *SPSV* | fraction | Solar penetration into thermal uses in post-1975 low-rise buildings of the service sector |
| *FDHS* | fraction | Approximate share of thermal energy demand in the service sector that can be met by a solar installation (the residual must be covered by a backup system) |
| *CHGNCF* | | Ratio of the amount of noncommercial fuels used in the current year relative to that in the base year |
| *EFF.H.SH[EFFHS(1)]*<br>*EFF.H.HW[EFFHS(2)]*<br>*EFF.H.CK[EFFHS(3)]*<br>*EFF.S.TH[EFFHS(4)]* | fraction | Efficiency of fossil fuel use relative to that of electricity use for thermal uses in the household/service sector (definition of categories as for *ELP.X.YY* above) |
| *EFFNCF* | fraction | Efficiency of noncommercial fuel use relative to that of thermal electricity uses |

## APPENDIX B3: DEFINITION OF DERIVED VARIABLES

| *Variable* | *Unit* | *Explanation* |
|---|---|---|
| GCF | $10^9\$1975$ | Gross fixed capital formation |
| GCFB | $10^9\$1975$ | Gross fixed capital formation, buildings |
| GCFM | $10^9\$1975$ | Gross fixed capital formation, machinery |
| PC | $10^9\$1975$ | Private consumption expenditure |
| TPCG | $10^9\$1975$ | Private consumption, durable and nondurable goods |
| TPCDG | $10^9\$1975$ | Private consumption, durable goods |
| TPCNDG | $10^9\$1975$ | Private consumption, nondurable goods |
| TPCSER | $10^9\$1975$ | Private consumption, services |
| YAG | $10^9\$1975$ | GPD contribution, agriculture |
| YB | $10^9\$1975$ | GDP contribution, construction |
| YMIN | $10^9\$1975$ | GDP contribution, mining |
| YMAN | $10^9\$1975$ | GDP contribution, manufacturing |
| YEN | $10^9\$1975$ | GDP contribution, energy sector (electricity/gas/water) |
| YSER | $10^9\$1975$ | GDP contribution, service sectors |
| VAMAN | $10^9\$1975$ | Value added, manufacturing |
| VAIG | $10^9\$1975$ | Value added contribution, basic material industries |
| VAM | $10^9\$1975$ | Value added contribution, machinery and equipment industries |

| *Variable* | *Unit* | *Explanation* |
|---|---|---|
| VAC | $10^9$ \$1975 | Value added contribution, nondurable goods industries |
| VAMIS | $10^9$ \$1975 | Value added contribution, miscellaneous industries |
| VA(1) | $10^9$ \$1975 | = YAG |
| VA(2) | $10^9$ \$1975 | = YB |
| VA(3) | $10^9$ \$1975 | = YMIN |
| VA(4) | $10^9$ \$1975 | = VAIG |
| VA(5) | $10^9$ \$1975 | = VAM |
| VA(6) | $10^9$ \$1975 | = VAC |
| VA(7) | $10^9$ \$1975 | = VAMIS |
| MFACM | Pcal | Motor fuel demand, agriculture/construction/mining |
| ELSACM | TWhr(e) | Electricity demand, agriculture/construction/mining |
| FFACM | Pcal | Thermal use of fossil fuels, agriculture/construction/mining |
| MFMAN | Pcal | Motor fuel demand, manufacturing |
| ELSMAN | TWhr(e) | Electricity demand for specific uses, manufacturing |
| USMAN(J), J = 1–4 | Pcal | Useful thermal energy demand in manufacturing for steam generation (J = 1), furnace/direct heat (J = 2), space/water heating (J = 3), and total (J = 4) |
| PMFF(J), J = 1–4 | fraction | Share of fossil fuels in USMAN(J) |
| PMEL(J), J = 1–4 | fraction | Share of electricity (conventional) in USMAN(J) |
| PMHP(J), J = 1–4 | fraction | Share of electricity (heat pump) in USMAN(J) |
| PMDH(J), J = 1–4 | fraction | Share of district heat in USMAN(J) |
| PMSS(J), J = 1–4 | fraction | Share of soft solar systems in USMAN(J) |
| PMCG(J), J = 1–4 | fraction | Share of onsite cogeneration in USMAN(J) |
| FFMAN | Pcal | Thermal use of fossil fuels in manufacturing |
| ELHMAN | Pcal | Thermal use of electricity in manufacturing |
| DHMAN | Pcal | District heat demand in manufacturing |
| SOLMAN | Pcal | Useful energy demand replaced by soft solar systems in manufacturing |
| COGSTH | Pcal | Total useful energy demand provided with cogeneration of electricity |
| COGEL | Pcal | Byproduct electricity from cogeneration in manufacturing |
| PSTEEL | $10^6$ tons | Total steel production |
| COKE | Pcal | Coke demand for pig-iron production |
| FEED | Pcal | Total feedstock consumption (i.e., use of energy sources as raw material) |
| MFIND | Pcal | Motor fuel demand in industry |
| ELACM | Pcal | Electricity demand, agriculture/construction/mining |
| ELMAN | Pcal | Electricity demand in manufacturing |

| *Variable* | *Unit* | *Explanation* |
|---|---|---|
| ELSIND | TWhr(e) | Electricity demand for specific uses, industry |
| ELIND | Pcal | Total electricity demand, industry |
| FFIND | Pcal | Thermal use of fossil fuels, industry |
| FINACM | Pcal | Final energy demand, agriculture/contruction/mining |
| FINMAN | Pcal | Final energy demand in manufacturing |
| FININD | Pcal | Final energy demand, industry |
| TKFRT | $10^9$ ton-km | Total ton-kilometers, freight (domestic) |
| TKTRU | $10^9$ ton-km | Ton-kilometers by truck, long-distance traffic |
| TKTRUL | $10^9$ ton-km | Ton-kilometers by truck, local traffic |
| TKTRA | $10^9$ ton-km | Ton-kilometers by train |
| TKBA | $10^9$ ton-km | Ton-kilometers by barge (or coastal shipping) |
| TKPIP | $10^9$ ton-km | Ton-kilometers by pipelines |
| TDTRU | Pcal | Diesel consumption by trucks, long-distance traffic |
| TDTRUL | Pcal | Diesel consumption by trucks, local traffic |
| TDTRAF | Pcal | Diesel consumption by freight trains |
| ELTRAF | TWhr(e) | Electricity consumption by freight trains |
| STCLF | Pcal | Coal consumption by freight trains |
| TDBA | Pcal | Diesel consumption by barges or for coastal shipping |
| TDPIP | Pcal | Diesel consumption by pipelines |
| TDFT | Pcal | Total motor fuel consumption, freight transportation |
| TELFT | TWhr(e) | Total electricity consumption, freight transportation |
| PKI | $10^9$ pkm | Total passenger-kilometers, intercity |
| PIC | $10^9$ pkm | Passenger-kilometers by car, intercity |
| PCT | $10^9$ pkm | Passenger-kilometers by public transportation, intercity |
| TPLA | $10^9$ pkm | Passenger-kilometers by plane (domestic) |
| TPTRA | $10^9$ pkm | Passenger-kilometers by train, intercity |
| TPBU | $10^9$ pkm | Passenger-kilometers by bus, intercity |
| TGIC | Pcal | Gasoline consumption of cars, intercity traffic |
| TDBU | Pcal | Diesel consumption by buses, intercity traffic |
| TDPLA | Pcal | Fuel consumption by planes (domestic flights) |
| TDTRAP | Pcal | Diesel consumption by passenger trains |
| ELTRAP | TWhr(e) | Electricity consumption by passenger trains (intercity) |
| STCLP | Pcal | Coal consumption by passenger trains |
| TELIP | TWhr(e) | Total electricity consumption, intercity passenger transportation |
| TMFIP | Pcal | Total motor fuel consumption, intercity passenger transportation |
| POU | $10^6$ persons | Total population in large cities (where mass transportation and district heating is feasible) |
| PKU | $10^9$ pkm | Total passenger-kilometers, intercity |
| PUC | $10^9$ pkm | Passenger-kilometers by car, intercity |
| PUMT | $10^9$ pkm | Passenger-kilometers by public transportation, intracity |
| TGUC | Pcal | Gasoline consumption by cars, intracity traffic |
| TELUC | TWhr(e) | Electricity consumption by electric cars (only considered for intracity traffic) |

| *Variable* | *Unit* | *Explanation* |
|---|---|---|
| TDMT | Pcal | Diesel consumption for public transportation, intracity |
| TELMT | TWhr(e) | Electricity consumption for public transportation, intracity |
| TMFUP | Pcal | Total motor fuel consumption, intracity traffic |
| TELUP | TWhr(e) | Total electricity consumption, intracity traffic |
| TMISMF | Pcal | Fuel consumption, international and military transportation |
| TELTR | TWhr(e) | Total electricity consumption for transportation |
| TMFTR | Pcal | Total motor fuel consumption for transportation |
| TCLTR | Pcal | Total coal consumption for transportation |
| ELTR | Pcal | Total electricity consumption for transportation, but with electricity expressed as thermal equivalent |
| FINTR | Pcal | Final energy consumption for transportation |
| TDEMDW | $10^6$ dwell | Dwellings demolished between previous and current model year |
| DWINCR | $10^6$ dwell | Net addition of dwellings between previous and current model year |
| DW | $10^6$ dwell | Total stock of dwellings |
| CONSDW | $10^6$ dwell | New constructed dwellings between previous and current model year |
| TPREDW | $10^6$ dwell | Stock of pre-1975 dwellings |
| TPSTDW | $10^6$ dwell | Stock of post-1975 dwellings |
| TDWSH | $10^6$ dwell | Total stock of dwellings in areas, where space heating is required |
| POSTDW(1) | fraction | Share of single family homes with central heating in post-1975 dwellings |
| POSTDW(2) | fraction | Share of apartments with central heating in post-1975 dwellings |
| POSTDW(3) | fraction | Share of dwellings without central heating in post-1975 dwellings |
| PRESH(1) | Pcal | Useful energy demand for space heating, pre-1975 single family homes with central heating |
| PRESH(2) | Pcal | Useful energy demand for space heating, pre-1975 apartments with central heating |
| PRESH(3) | Pcal | Useful energy demand for space heating, pre-1975 dwellings without central heating |
| POSTSH(1) | Pcal | Useful energy demand for space heating, post-1975 single family homes with central heating |
| POSTSH(2) | Pcal | Useful energy demand for space heating, post-1975 apartments with central heating |
| POSTSH(3) | Pcal | Useful energy demand for space heating, post-1975 dwellings without central heating |
| SH | Pcal | Useful energy demand for space heating |
| HW | Pcal | Useful energy demand for water heating |
| COOK | Pcal | Useful energy demand for cooking |
| ACH | Pcal | Useful energy demand for air-conditioning |

| *Variable* | *Unit* | *Explanation* |
|---|---|---|
| ELAP | TWhr(e) | Specific electricity consumption in dwellings (i.e., for purposes other than space and water heating, cooking, and air-conditioning) |
| PLSER | fraction | Service sector share of labor force |
| LSER | $10^6$ workers | Numbers of workers in the service sector |
| TDEMAR | $10^6 m^2$ | Service sector floor area demolished between previous and current model years |
| ARINCR | $10^6 m^2$ | Net addition of service sector floor area between previous and current model years |
| TAREA | $10^6 m^2$ | Total service sector floor area |
| CONSAR | $10^6 m^2$ | Newly constructed service sector floor area between previous and current model years |
| AREAO | $10^6 m^2$ | Pre-1975 service sector floor area |
| AREAN | $10^6 m^2$ | Post-1975 service sector floor area |
| TARSH | $10^6 m^2$ | Total service sector floor area, where space heating is required |
| HSERVO | Pcal | Useful energy demand for thermal uses, pre-1975 service sector buildings |
| HSERVN | Pcal | Useful energy demand for thermal uses, post-1975 service sector buildings |
| THSERV | Pcal | Total useful energy demand for thermal uses in the service sector |
| ACSV | Pcal | Useful energy demand for air-conditioning in the service sector |
| ELSVO | TWhr(e) | Specific electricity demand, pre-1975 service sector buildings |
| ELSVN | TWhr(e) | Specific electricity demand, post-1975 service sector buildings |
| ELSV | TWhr(e) | Total specific electricity demand of the service sector |
| USHS(J), J = 1–4 | Pcal | Useful energy demand for space heating (J = 1), water heating (J = 2), cooking (J = 3) in households and thermal uses in the service sector (J = 4) |
| FINNCF | Pcal | Final energy from noncommercial fuels (e.g., fuelwood, wastes) |
| USNCF | Pcal | Useful energy from noncommercial fuels |
| PNCFH | fraction | Fraction of useful energy demand for space and water heating and cooking in households supplied by noncommercial fuels |
| PHSNCF(J), J = 1–4 | fraction | Share of noncommercial fuels in USHS(J) |
| PHSFF(J), J = 1–4 | fraction | Share of commercial fossil fuels in USHS(J) |
| PHSEL(J), J = 1–4 | fraction | Share of electricity (conventional) in USHS(J) |
| PHSHP(J), J = 1–4 | fraction | Share of electricity (heat pumps) in USHS(J) |

| *Variable* | *Unit* | *Explanation* |
|---|---|---|
| PHSDH(J), J = 1–4 | fraction | Share of district heat in USHS(J) |
| PHSSS(J), J = 1–4 | fraction | Share of soft solar systems in USHS(J) |
| ELHHS | Pcal | Electricity consumption for thermal uses in the household/service sector |
| DHHS | Pcal | District heat consumption in the household/service sector |
| SOLHS | Pcal | Useful energy demand replaced by soft solar systems in the household/service sector |
| FFHS | Pcal | Commercial fossil fuel consumption in the household/service sector |
| USCOOL | Pcal | Useful energy demand for cooling in the household/service sector |
| ELAC | Pcal | Electricity demand for air-conditioning in the household/service sector |
| ELSPHS | TWhr(e) | Electricity demand for specific uses in the household/service sector |
| ELHS | Pcal | Total electricity consumption of the household/service sector |
| FINHS | Pcal | Commercial final energy demand of the household/service sector |
| FHSPNC | Pcal | Commercial plus noncommercial final energy demand of the household/service sector |
| FF | Pcal | Total thermal use of fossil fuels |
| DH | Pcal | Total district heat demand |
| SOL | Pcal | Total solar energy demand |
| ELEC | Pcal | Total electricity demand |
| TMF | Pcal | Total motor fuel demand |
| COALSP | Pcal | Specific uses of coal |
| ENERGY | Pcal | Total commercial final energy demand |
| ENPNCF | Pcal | Total commercial plus noncommercial final energy demand |

## APPENDIX C: DEFINITIONS OF MACROECONOMIC SECTORS IN TERMS OF ISIC* CATEGORIES

| | Regions I, II, III | Regions IV, V, VI |
|---|---|---|
| Agriculture | ISIC 1 | ISIC 1 |
| Construction | ISIC 5 | ISIC 5 |
| Mining | – | ISIC 2 |
| Manufacturing | ISIC 3<br>–ISIC 353, 354<br>+ISIC 2<br>–ISIC 21, 22 | ISIC 3 |
| Energy | ISIC 4<br>+ISIC 21, 22<br>+ISIC 353, 354 | ISIC 4 |
| Services** | ISIC 6, 7, 8, 9 | ISIC 6, 7, 8, 9 |
| Manufacturing subsectors: | | |
| Basic materials | ISIC 341, 351, 352, 36, 37<br>+ISIC 2<br>–ISIC 21, 22 | ISIC 341, 351, 352<br>+ISIC 353, 354<br>+ISIC 36, 37 |
| Machinery and equipment | ISIC 38 | ISIC 38 |
| Nondurables | ISIC 31, 32, 33, 342, 355, 356, 39 | ISIC 31, 32, 33<br>+ISIC 342, 355, 356<br>+ISIC 39 |

*International Standard Industrial Classification of all Economic Activities, Statistical Paper Series No. 4 Rev. 2, UN New York (1968).

**For Region II, a rough estimate of services belonging to the nonmaterial sphere has been included.

# ABSTRACTS OF OTHER IIASA PUBLICATIONS

Long, L.H., and W.H. Frey, Migration and Settlement: 14. United States. IIASA Research Report RR-82-15, April 1982.

The comparative analysis of national patterns of interregional migration and spatial population growth is being carried out by an international network of scholars who are using methodology and computer programs developed at IIASA. Like many countries, the US is experiencing a change in patterns of migration and natural increase. Adopting the traditional US Census Bureau's four-region aggregation, Long and Frey examine the multiregional demographic implications of this emerging spatial reallocation process. Special emphasis is placed on intraregional city–suburb redistribution, and a model is presented that links such local intraregional shifts with the national interregional redistribution within the US.

Doblin, C.P., The Growth of Energy Consumption and Prices in the USA, FRG, France, and the UK, 1950–1980. IIASA Research Report RR-82-18, May 1982.

This paper examines data on gross domestic product (GDP), industrial output, energy consumption, and the prices of fuels and electricity in four developed countries (the USA, the FRG, France, and the UK) for the period 1950–1980. The prices are taken in current values and adjusted for general inflation; they are monitored by broad sectors of the economy (industry, households, and transportation), and for electricity and groups of fuel commodities. The results are presented in four parts: a discussion of the major observations; the data presented in tabular form; a set of graphs showing the growth of energy consumption and prices; and a listing of the concepts, definitions, and sources of the variables selected for study.

Snickars, F., and A. Granholm, A Multiregional Planning and Forecasting Model with Special Regard to the Public Sector. IIASA Research Report RR-82-21, May 1982. Reprinted from *Regional Science and Urban Economics*, Vol. 11, 1981, pp. 377–404.

Despite the magnitude of the public sector and its rapid growth, most multiregional economic models are lacking public sector content. This paper aims at incorporating some of the roles of the public sector in the regional development. It is done within the framework of a multiregional optimization model for the allocation of private and public investment, production, employment (and population) over economic sectors and regions. By choosing appropriate objective functions, the model may be used for either planning or forecasting purposes. In the model the focus is on the public sector as a service and provision body and as a provider of public infrastructure. Its role as an agent for transfer payments is not stressed. The capacities of the model are illustrated by means of an example concerning Swedish regional development 1977–1983.

Maier, H., and H.-D. Haustein, Innovation, Efficiency Cycle, and Strategy Implications. IIASA Research Report RR-82-22, May 1982.
Reprinted from *Technological Forecasting and Social Change*, Vol. 17, 1980, pp. 35–49.

Innovation research is now in its third stage, in which most attention is given to the efficiency cycle of industries. The five stages of this efficiency cycle (takeoff, rapid growth, maturation, saturation, and crisis) are very important for the firm's strategy and national innovation policy. Innovation policy should take into account societal goals and objectives. A social opportunity analysis is especially important for determining future innovation fields, identifying new alternatives for structural change, and solving problems facing national economies and the entire world economy. This paper tries to identify the universal and global challenges facing national innovation policy and firm strategy in many countries. The conclusion is that we need a relationship between innovation policy and firm strategy that is able to give innovations a more concrete orientation toward human needs; to create social control procedures for unintentional, indirect, or delayed disadvantages of technology; to secure the interlinkage between technological and social innovation; and to contribute significantly to solving global problems. In this context we discuss the tasks critical to improving the relationship between national innovation policy and firm strategy: 1, consideration of the different roles of basic, improvement, and pseudo-innovations; 2, information about future fields of innovation; 3, exploration of the different side effects of innovation; 4, a strengthening of the scientific and educational infrastructure for innovation; 5, improvement in the abilities of firms and society to deal with new circumstances and situations by developing new procedures of social and organizational innovative learning; 6, the realization that government actions concerning innovation can cause very different results in the different stages of the innovation process; 7, the global dimension of innovation.

# BIOGRAPHIES

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Alois Hölzl received his diploma in Applied Mathematics from the Technical University in Vienna in 1976. He joined IIASA's Resources and Environment Area in 1975 as a research assistant. In 1978 he became a research scholar and joined the Energy Systems Program. His activity was devoted to energy demand modeling, first on a case study for Austria, and later for the developed world regions as part of the Energy Systems Program. He is now a member in the organizing department of the Austrian National Oil and Gas Company.

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Arshad M. Khan gained his Ph.D. in physics at the University of Birmingham, UK in 1964. In 1968 he joined the Pakistan Institute of Nuclear Science and Technology and did experimental work on the nuclear physics of neutron capture reactions. At the same time, Dr. Khan was closely associated with the science and technology planning activities in Pakistan. He joined IIASA's Energy Systems Program in 1978 to study the long-term energy requirements of developing countries, and the options and alternative strategies that could be applied to their particular circumstances. He is now Head of the Applied Systems Analysis Group at the Pakistan Atomic Energy Commission.

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Hans-Holger Rogner received a masters degree in engineering in 1975 and a Ph.D. in engineering economics in 1982, both from the University of Karlsruhe in the Federal Republic of Germany. Before joining IIASA's Energy System Program in 1975, Dr. Rogner carried out research on energy strategies in transition periods at the Nuclear Research Center in Karlsruhe. At IIASA he has focused on energy supply modeling, analysis of the energy sector's capital requirements, and, most recently, macroeconomic modeling. Dr. Rogner has participated in multidisciplinary studies of long-term energy demand and supply systems for the European Community. He has also assisted research teams in Bulgaria, Egypt, and China in constructing and implementing energy and economic models.

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**CONTENTS**

**IN FORTHCOMING ISSUES:**

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M. JAMEEL Energy and Agriculture in Pakistan

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