THE ECONOMIC IMPACT MODEL

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RR-79-8
October 1979

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PREFACE

The Energy Systems Program (ENP) of the International Institute for Applied Systems Analysis (IIASA) complements the efforts of other groups concerned with the question of how the world might move from an energy system based on oil and gas to one relying on essentially infinite, but highly capital intensive, energy resources. The ENP has been concerned with the identification and comparative evolution of strategies for this energy transition. The relevant modeling activity has been carried out under the project "Comparison of Energy Options, a Methodological Study," sponsored jointly by the United Nations Environment Programme (UNEP) and IIASA.

In this context, an initial version of the economic impact model (IMPACT) was developed at the Siberian Power Institute of the Siberian Branch of the USSR Academy of Sciences in Irkutsk. The model was originally designed to study the influence of the development of the energy sector on energy-related sectors of the national economy. Subsequently, the model was brought to IIASA where it was revised to focus on the identification and comparison of long-term regional and global energy strategies in the transition period of 15 to 50 years from now. The possible influence of any given energy strategy on the economy is evaluated in terms of capital investment, manpower, materials, and natural resources that are needed to develop not only the energy supply system (ESS) but also the energy-related sectors of the economy.

This report describes IMPACT as it exists at IIASA, explains the computer program, and includes a user guide for implementing this methodology. It was stimulated by the interest in the model shown by a number of groups, among them the Bechtel Corporation in the U.S.; the Program

Group for Systems Research and Technological Development at the Nuclear Research Installation in Juelich, Federal Republic of Germany; and the Bulgarian Ministry of Energy in Sofia.

The authors wish to thank Professor Clopper Almon for his valuable suggestions, and Jeanne Anderer and Paul Basile for their help in preparing this report.

CONTENTS

1 INTRODUCTION

The energy supply system (ESS) is an essential component of an economy, although not a relatively large one. Attention has therefore been given recently to the study of the energy/economy interaction. The Energy Systems Program (ENP) at IIASA seeks, in its modeling work, to focus on this issue. The economic impact model (IMPACT) described in this report assesses the direct and the indirect requirements of alternative energy supply scenarios for capital investment, manpower, equipment, materials, and certain scarce resources. These data are used to evaluate the effects of the energy scenarios on the economy.

1.1 THE IIASA ENERGY SYSTEMS PROGRAM

A few words about the Energy Systems Program are in order. ENP focuses on the so-called *energy transition*: the slow, but major shift from the present energy system to a future sustainable one. The Program's considerations are primarily long term, spanning a horizon of 15 to 50 years from now – the period that IIASA believes encompasses the energy transition. The considerations are necessarily global: the present, large-scale supply and use of energy mandates an unprecedented degree of global interdependence. Global questions must be considered pivotal to all future energy studies.

A number of preliminary views and assumptions have helped to define IIASA's approach to the study of the energy problem.

- Energy systems are currently based on cheap oil and gas supplies; a gap between the world's expectations of such fuels and producers' ability or willingness to supply these amounts is expected in the late 1980s.

- As a result, there will almost certainly be continued increases in world energy prices; this new environment contrasts with that of the past energy scene during which energy prices were either constant or, in some cases, decreasing.
- Scientific and technological progress will contribute to a new capital intensiveness in energy systems that could have large feedback on economies. Large-scale energy investments are essential in the near and the long-term future.
- Concern for the environment will continue to influence global decisions in the energy arena.

The focus of the Energy Systems Program is the transition period – in particular the period of strategic investments beyond the year 2000. We hope to study that period by, in part, looking beyond it to the year 2030 or so, and then evaluating alternative paths through the transition. The computer modeling effort of the ENP is designed to implement, with some degree of comprehensiveness, this approach.

The goals of the IIASA energy modeling activity are fourfold:

- To study the long-term, dynamic (transitional), and strategic dimensions of regional and global energy systems
- To explore the embedding of such future energy systems and strategies into the economy, the environment, and society
- To develop a framework for assessing the global implications of long-term regional or national energy policies and, within this context, to evaluate methods for phasing the "best" energy strategies into various world regions
- To evaluate alternative strategies – to compare options – of a physical and technological kind, including their economic impacts

1.2 DIRECT AND INDIRECT REQUIREMENTS OF AN ENERGY SUPPLY STRATEGY

In the event of a rapid transition to the use of new, capital intensive energy resources, the total requirements – direct and the indirect – of a given energy supply strategy must be evaluated. The *direct requirements* are evaluated in terms of capital investment, manpower, materials, and equipment needed to construct and operate the energy facilities for implementing a national or a regional energy program. The *indirect requirements* refer to the resource and investment requirements of the energy-related sectors whose development is induced by the development of the ESS. In the event of such an energy transition, the additional investment in the machinery, metallurgy, construction, and other energy-related sectors could amount to 30 percent or more of the direct investment in the ESS. In this case, the indirect requirements for manpower and specific materials could exceed the direct input (Kononov and Makarov, 1975). Thus focusing only on the direct requirements can lead to serious underestimation and incomplete identification of possible constraints.

The simplest way of estimating the indirect influence of a given energy strategy on energy-related sectors is to apply a modified static input/output model: the direct material expenditures for constructing and operating the ESS could be represented as fixed final consumption. This approach was used by Bullard and Pilati (1975) of the University of Illinois for evaluating the construction requirements of the Project Independence scenario. However, this approach does not allow the estimation of the effect of the development of the ESS on the dynamics of capacities in energy-related sectors and on indirect capital investment. Accordingly, it does not take into account the relations and expenditures induced by capital investments in energy-related sectors.

Therefore, the above approach cannot give satisfactory results under conditions of rapid development of capital intensive energy resources and technologies. In this case a special model is needed.

1.3 DEVELOPMENT OF IMPACT

A dynamic, multisectoral model was constructed in 1972 at the Siberian Power Institute in Irkutsk, USSR; the model takes into account: (a) the construction lags – the gap in time between the start of investment and putting into operation of production capacities, and (b) the equipment and material consumption for each year of the construction period; it describes the intersectoral relations in both cost and physical terms. The model is convenient for computing and serves to investigate the influence of sizeable long-term changes in the technology, structure, and rates of energy development upon other, related branches of the national economy. Some characteristics of the Irkutsk model are given in Table 1 in the standard format of IIASA model surveys. A more detailed description can be found in Kononov (1976; 1972).

TABLE 1 Model of the external production relations of the energy supply system in the Soviet Union.

The model	Yu.D. Kononov, V.Z. Tkachenko, 1972 (Kononov, 1972; 1976). Siberian Power Institute, Irkutsk. Model of the external production relations of the energy supply system.
Subject and goal	• Relations of the energy system with metallurgy, engineering, construction industry, transport, and other sectors directly or indirectly contributing to its development by their products. • Approximate estimation of the influence of a changed pattern and development rate of energy production, and of changes in the technology of production or transportation of particular energy resources, on the development of related branches and on the national economy's total expenses (in terms of investment, labor and materials).
System described	The model covers all the main fuel deposits, groups of electric power stations and energy-production methods, and those industrial, transportation and construction sectors which largely depend for their progress on the development alternatives of energy production. The model takes into account that this dependence is complex and nonlinear and that some related branches have to be developed in advance of energy production. Extra demand for particular industrial products is assumed to be met either from expanded production capacities or from increased imports.
Area: Time	15 to 20 years ahead, described dynamically (in separate periods over the years considered).
Area: Space	The country as a whole.
Modeling techniques	The model belongs to the dynamic input–output models, explicitly accounting for lags between the start of investment and putting into operation of production capacities. It consists of linear and nonlinear equations, describing for each year of the period concerned: balances of the production of individual products and services and their consumption in operating and building the energy systems and related branches; and the conditions for introducing extra capacities in related branches. An iterative algorithm is used to resolve the model.
Input data	• Outputs of particular energy resources and commissioning of capacities in the energy system, specified by year; methods and ranges of energy transportation.

TABLE 1 *Continued.*

	• Import of individual industrial products for power production development • Export of individual industrial products compensating for hard-currency outlays for imported power resources. • Coefficients (rates) of material expenses for operation and construction in the energy system and related branches. • Standard time rates for building and putting into operation of individual production units. • Capital investment per unit of capacity increment in all the industries covered by the model. • Allocation of investment by year of building. • Labor-intensiveness of particular products and building projects.
Output data	Requisites for implementing the given development alternative of the energy system: • Outputs (direct and indirect expenses) of various industrial products, construction and transportation services. • Commissioning of capacities in related branches. • Priority of development of individual branches. • Direct and indirect (related) investment and manpower.
Observations	The model serves as a tool to study the effects produced by major and prolonged changes in ESS development on other economic branches (it consists of some 50 sectors and industries). It is also of help in long-range planning and forecasting for estimating the constraints imposed on ESS development by related branches; investigating the uncertainty zone of this development; and tentatively assessing the set of measures and the dates for implementing particular energy alternatives.

SOURCE: Beaujean and Charpentier (1976, p.2).

At IIASA, the Irkutsk model was developed further and adjusted to purposes of identification and comparison of long-range regional energy strategies in the transition period. This modified version of the model, called the economic impact model (IMPACT), differs from the analogue Irkutsk model in the following ways:

- The time horizon has been extended in IMPACT to include the period 15 to 50 years from now.
- IMPACT has been generalized to include new energy technologies (e.g., fast breeder reactors, coal gasification and liquefaction, solar and geothermal energy, hydrogen production).

- The composition and the number of energy-related sectors have been revised in IMPACT.
- The additional production of export goods, compensating for hard currency outlays for imported fuel, has been taken into account in IMPACT.
- IMPACT evaluates the direct and the indirect WELMM (Water, Energy, Land, Materials, and Manpower) expenditures and potential environmental impacts.
- The computer program of IMPACT has been improved.

1.4 MODEL ASSUMPTIONS

IMPACT gives the range of total (direct and indirect) expenditures. For the minimum range, it has been assumed that the ESS can be developed without putting into operation the production capacities of the energy-related sectors; enterprises producing equipment related to energy supply and use – such as turbogenerators, reactors, and mining equipment – are the exception. For the maximum values of total expenditures, there are no limitations on putting into operation the capacities of the energy-related sectors, and the requirements for the additional development of the machinery, metallurgy, and chemical industries as well as for other related branches of the national economy have been considered.

IMPACT assumes that capacity in the first year of each scenario is adequate for the level of energy output. (For the long-run scenarios used at IIASA, capacity for the first 5 years or so is nearly the same for all scenarios.)

IMPACT also assumes that imports of capital equipment are given exogenously. Thus in a region where most of the capital equipment is locally produced, the scenario should calculate a minimum amount of imports. However, in a region where there is large-scale importing of technically advanced energy equipment, the scenario should specify the equipment as imports so that investment in domestic industries to produce such equipment will not be generated by the model.

1.5 MODEL SCOPE

Explicitly, IMPACT can answer the following questions:

- What direct capital investment would be needed to implement a given energy strategy? When?

- What direct expenses of materials, equipment, manpower, and scarce natural resources would be required to construct and operate new energy facilities? When?

Roughly, IMPACT can address the following questions:

- What production capacities in energy-related sectors would be required to implement a given energy strategy? When?
- What indirect capital, manpower, materials, and scarce natural resources would be needed to implement a given energy strategy? When?
- How different are the total (direct and indirect) requirements of different energy strategies for limited national and natural resources?
- What are the potential direct and indirect environmental impacts of a given energy strategy?

IMPACT can be helpful in answering the following questions:

- How will the transition to essentially infinite, but highly capital intensive, energy resources affect macroeconomic indices?
- What capital, manpower, and material resource categories are potential bottlenecks to implementing a given energy strategy?
- Is a given energy strategy feasible? If not, what can be done to make it feasible?

At this point we should state what IMPACT can *not* do. IMPACT does not calculate price changes resulting from various scenarios, and does not assess the effects of such changes on final demand or on intermediate demand. Moreover, IMPACT does not check the capacity requirements of energy-related sectors in the first year against existing stocks. Such checking is not possible since IMPACT is not a model of the whole economy. For example, it would be meaningless to compare cement production generated by IMPACT with cement capacity, because the production estimates by IMPACT do not include the use for residential or highway construction.

1.6 LINKAGE OF IMPACT WITH OTHER ENERGY MODELS

IMPACT is an integral part of the IIASA set of energy models which has been designed for studying the long-term, dynamic, and regional and global aspects of large-scale energy systems (Figure 1). The critical question concerned in the modeling is whether economies can afford the requisite expenditures of time and capital to achieve alternative energy strategies during the long-term transition to sustainable energy systems. The several individual models and their interrelationships were developed with these considerations in mind. The design and application of the IIASA set of energy models is discussed by Paul Basile, Assistant Leader of the ENP, in a report that is in preparation.

IMPACT provides the evaluation of the requirements of a given energy strategy in terms of capital investment, manpower, and other scarce resources. This output is then used to assess the possible impact of the strategy on some macroeconomic indices.

At IIASA, for example, a one-sector macroeconomic model (MACRO) has been developed in order to evaluate the possible dynamics

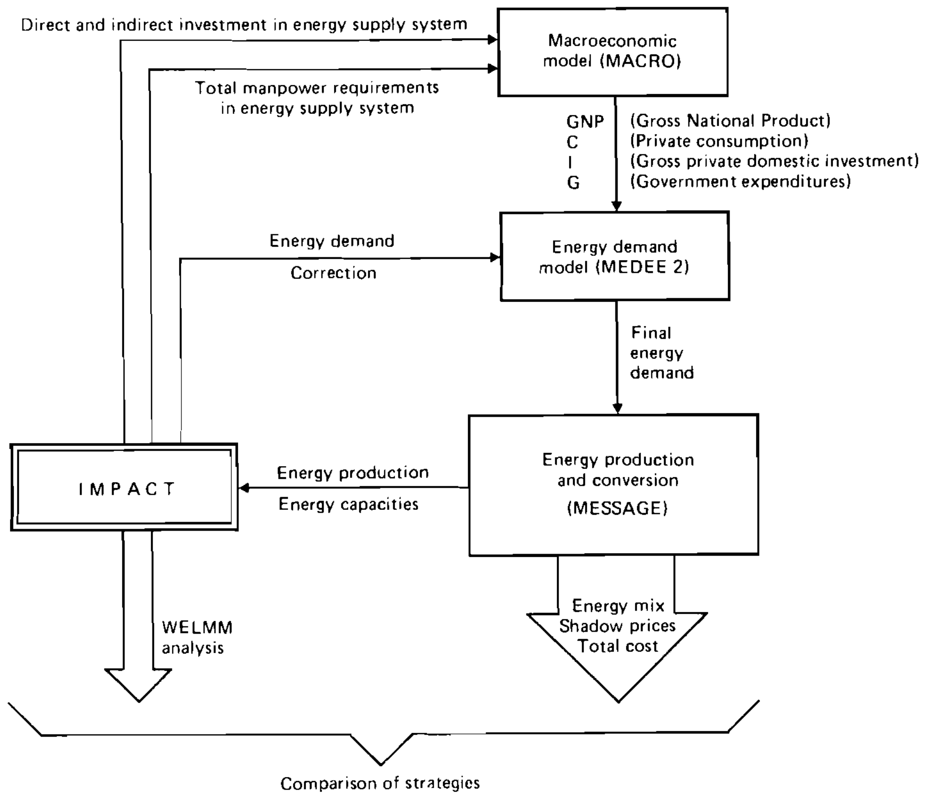

FIGURE 1 Linkage of IMPACT with other IIASA energy models.

of gross national product (GNP), private consumption, gross private domestic investment, and government expenditure (Rogner, 1977). By linking IMPACT with MACRO (Figure 1), it is possible to:

- Compare the designed share of energy in gross private domestic investment and employment with historical data, and thereby assess the possible difficulties of providing a given energy strategy with capital investment and manpower
- Correct corresponding variables of MACRO and evaluate roughly the possible impact of a given energy strategy on GNP and private consumption growth rates

Theoretically, by using a *multisectoral* macroeconomic model, the accuracy and completeness of the economic impact evaluation would be increased.

IMPACT is unique as a model for evaluating the energy/economy linkage in this manner. One of the few exceptions is the Energy Supply Planning Model (Carasco *et al.*, 1975), developed by the Bechtel Corporation in the U.S. Bechtel's model determines the *direct* requirements for capital, manpower, materials, and equipment associated with the construction and operation of energy facilities required to implement a given national or regional energy program, but it does not take into account the *indirect* requirements. IMPACT can be used in conjunction with the Bechtel Energy Supply Planning Model: the input data for IMPACT are the direct requirements of the ESS for materials and equipment, which represent output from the Bechtel model.

2 GENERAL DESCRIPTION OF IMPACT

The inputs to IMPACT are the time paths of energy production by type of energy and by method of production. This input can be provided by an energy supply model – for instance, the IIASA MESSAGE model. If needed, IMPACT, employing the user's specification, can disaggregate a given strategy and evaluate requirements for new capacities for transportation and conversion of energy resources.

2.1 MODULES

The model is divided into five modules (Figure 2).

The *first module* calculates the direct material and equipment requirements ($Y_e(t)$) for the construction and operation of energy facilities for implementing a given energy supply strategy. The ESS is represented in the prototype model by 58 energy activities; Table 2 groups these activities according to the energy source. A list of the energy activities included in IMPACT is given in Appendix A.

The first module may be omitted if IMPACT works in conjunction with the Bechtel Energy Supply Planning Model. In this case, the input data for IMPACT are the direct material and equipment requirements of the ESS, which represent output from the Bechtel model.

The *second module*, using an I/O technique, describes the relationship between the ESS and the energy-related sectors. The module calculates the required production output in the energy-related sectors needed to support energy development ($X_1(t)$). The prototype model includes 36 sectors and types of industrial products (see Appendix A). For these sectors the following assumptions were made:

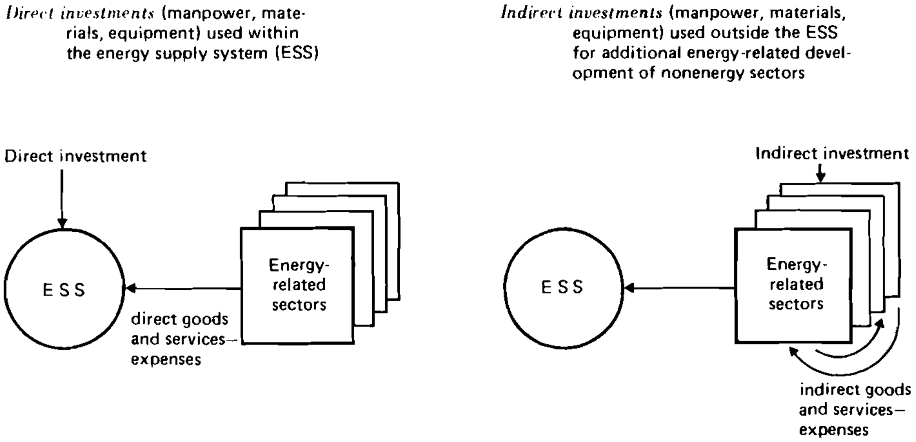

FIGURE 2 Definition of terms for IMPACT.

- Products are manufactured by a single method – that is, there is no choice of technology or distribution. Where known, the most progressive production methods are assumed.
- The coefficients of material, capital, and manpower inputs per unit of production or capacity expansion do not depend on the scale of production.

TABLE 2 Energy activities in IMPACT.

Energy source	Number of activities
Oil and oil shale extraction and refining	7
Gas extraction	4
Coal mining	3
Synthetic fuels from coal	4
Hydrogen production	3
Fuels, transportation, storage, and distribution	12
Conventional power plants	4
Nuclear power plants	3
Nuclear fuel cycle	9
Geothermal power complex	1
Solar power plants	1
Electricity transmission and distribution	1
Miscellaneous	6

The *third module* determines capacity expansion requirements of energy-related sectors ($Z_1(t)$). The additional capacity required by the end of year t is the difference between estimated output in year $t + 1$ and actual production in the previous peak year.

The *fourth module* estimates the capital investment required for the capacity expansion determined in module 3. Capital investment in any year depends upon capacity expansion in the current and future years and on replacement requirements. The feedback between modules 4 and 2 is achieved in IMPACT by means of an iterative procedure, which is described later in this report. In a mathematical sense, modules 2, 3, and 4 represent an indivisible system of equations.

The *fifth module* estimates the WELMM requirements of the ESS and evaluates the effects of water and air pollution on the system.

3 MATHEMATICAL DESCRIPTION OF IMPACT

Matrix notation is used throughout the section. The letters t or τ in parenthesis denote vector-valued time functions. A bar denotes an exogenously given input.

3.1 THE EQUATION SYSTEM OF IMPACT

The direct requirements of the ESS for products of energy-related sectors are expressed as

$$Y_e(t) = A_1 \overline{X}_e(t) + \sum_{\tau=t}^{t+\hat{\tau}} F_1{}^{(\tau-t)} \overline{Z}_e(\tau) \tag{1}$$

where

- $Y_e(t)$ is the vector of direct investment and operational requirements of the ESS for products of energy-related sectors in the year t
- $\overline{X}_e(t)$ is the vector of annual energy production in the year τ
- $\overline{Z}_e(t)$ is the vector of required additional capacities of the ESS in the year t
- A_1 is the matrix of contribution coefficients of energy-related sectors to the construction and operation of energy production per unit of activity
- $F_1{}^{(\tau-t)}$ is the matrix of contribution coefficients of energy-related sectors in the year t to putting into operation the additional capacities of the ESS in the year τ ($t \leqslant \tau \leqslant t + \hat{\tau}$)
- $\hat{\tau}$ is the lead time (construction lag)

Total (direct and indirect) material and equipment requirements of the ESS are expressed as

$$X_1(t) = A_2 X_1(t) + A_3 X_2^{in}(t) + Y_e(t) \tag{2}$$

where

A_2 is the matrix of input/output coefficients
A_3 is the matrix of materials and equipment requirements coefficients per unit of investment in energy-related sectors
$X_1(t)$ is the vector of output in energy-related sectors
$X_2^{in}(t)$ is the vector of indirect capital investments in energy-related sectors

Direct capital investment in the ESS is expressed as

$$X_2^d(t) = \sum_{\tau=t}^{t+\hat{\tau}} F_2^{(\tau-t)} \overline{Z}_e(\tau)$$

Indirect capital investment in the ESS is expressed as

$$X_2^{in}(t) = \sum_{\tau=t}^{t+\hat{\tau}} F_3^{(\tau-t)} Z_1(\tau)$$

Total (direct and indirect) capital investment in the ESS is expressed as

$$X_2^{(t)} = X_2^d(t) + X_2^{in}(t) \tag{3}$$

where

$F_2^{(\tau-t)}$, $F_3^{(\tau-t)}$ are, respectively, the matrices of capital investment coefficients in the year t to put into operation the additional capacities of the ESS and energy-related sectors in the year τ
$Z_1(t)$ is the vector of new additional capacities in the energy-related sectors in the year t
$X_2^d(t)$ is the vector of direct capital investment in the ESS

Vector $Z_1(t)$, with vector components $Z_1^{(1)}, \ldots, Z_1^{(k)}$, must satisfy the following conditions:*

*In order to take into account *installed* capacity requirements this expression can be replaced by

$$Z_1^{(i)}(t) = \begin{cases} \min\limits_{\tau \leq t} \left[X_1^{(i)}(t+1) - \dfrac{X_1^{(i)}(\tau)}{(1-p)^{t-\tau+1}} \right] & \text{if this value is positive;} \\ 0 & \text{otherwise} \end{cases}$$

for every $i \in \{1, 2, \ldots, k\}$ where p is the rate of replacement.

$$Z_1{}^{(i)}(t) = \begin{cases} \min\limits_{\tau \leqslant t} \left[X_1{}^{(i)}(t+1) - X_1{}^{(i)}(\tau) \right] & \text{if this value is positive;} \\ 0 & \text{otherwise} \end{cases}$$

for every $i \in \{1, 2, \ldots, k\}$.

Vector notation is used in the model for simplicity reasons. This equation is therefore written as

$$Z_1(t) = \max \left[\min\limits_{\tau \leqslant t} \; (X_1(t+1) - X_1(\tau)); 0 \right] \tag{4}$$

The structure of IMPACT is shown in Figure 3.

3.2 AUXILIARY EQUATIONS OF IMPACT

The model also includes an equation for calculating the direct and the indirect expenses of the WELMM resources. This equation is written as

$$X_3(t) = A_4 \overline{X}_e(t) + A_5 X_1(t) + A_6 X_2{}^{in}(t) + \sum_{\tau = t}^{t + \hat{\tau}} F_4{}^{(\tau - t)} \overline{Z}_e(\tau) \tag{5}$$

where

- $X_3(t)$ are the WELMM expenditures in the year t
- A_4 is the matrix of direct operational WELMM coefficients
- A_5 is the matrix of indirect operational WELMM coefficients of energy-related sectors
- A_6 is the matrix of indirect constructional WELMM coefficients of energy-related sectors
- $F_4{}^{(\tau - t)}$ is the matrix of direct constructional WELMM coefficients in the year t to put into operation new energy capacities in the year τ

Equations for evaluating air and water pollutant emissions of the ESS and the energy-related sectors can be written analogically.

The drivers for IMPACT's relations are $\overline{X}_e(t)$ and $\overline{Z}_e(t)$; these exogenous variables can be obtained from an energy supply model (e.g., the IIASA MESSAGE model).

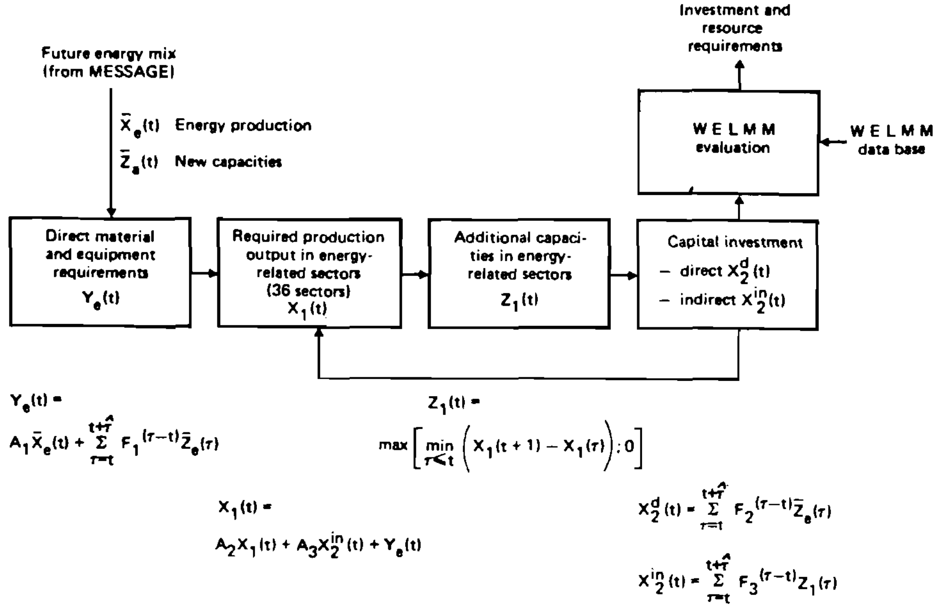

FIGURE 3 Structure of IMPACT.

3.3 THE ALGORITHM

Symbol A is used to denote the matrix composed of matrices $A_1, A_2, \ldots, A_6$ as follows:

$$A = \begin{bmatrix} A_1 & A_2 & A_3 \\ 0 & 0 & 0 \\ A_4 & A_5 & A_6 \end{bmatrix}$$

The zero matrices contain as many rows as the number of columns in matrix A_3.

Similarly, symbol $F^{(\tau-t)}$ is used to denote the matrix composed of matrices $F_1^{(\tau-t)}, \ldots, F_4^{(\tau-t)}$ as follows:

$$F^{(\tau-t)} = \begin{bmatrix} F_1^{(\tau-t)} & 0 & 0 \\ F_2^{(\tau-t)} & F_3^{(\tau-t)} & 0 \\ F_4^{(\tau-t)} & 0 & 0 \end{bmatrix}$$

The zero matrices in the third column contain as many columns as the number of columns in matrix A_3.

The detailed structures of matrices A and $F^{(\tau - t)}$ $(t \leqslant \tau \leqslant t + \hat{\tau})$ are given in Figures 4 and 5. By means of these new matrix symbols the model can be written in the following reduced form:

$$X^*(t) = AX(t) + \sum_{\tau=t}^{t+\hat{\tau}} F^{(\tau - t)} Z(\tau)$$

$$Z_1(t) = \max \begin{bmatrix} \min\limits_{\tau \leqslant t} (X_1(t+1) - X_1(\tau)); 0 \end{bmatrix} \tag{6}$$

where

$$X^*(t) = (X_1(t), X_2(t), X_3(t))$$
$$X(t) = (\overline{X}_e(t), X_1(t), X_2{}^{in}(t))$$
$$Z(t) = (\overline{Z}_e(t), Z_1(t), 0)$$

This form of the model is important because the data for the computer program must be prepared as A and $F^{(0)}, \ldots, F^{(\hat{\tau})}$ matrices.

Since $\overline{X}_e(t)$ and $\overline{Z}_e(t)$ are exogenous variables, and vector $X_3(t)$ depends on vectors $X_1(t)$ and $X_2(t)$ (but does not influence them), the model may be written in the following reduced form:

$$X(t) = AX(t) + \sum_{\tau=t}^{t+\hat{\tau}} F^{(\tau - t)} Z(\tau) + Y(t) \tag{7}$$

$$Z_1(t) = \max \begin{bmatrix} \min\limits_{\tau \leqslant t} (X_1(t+1) - X_1(\tau)); 0 \end{bmatrix}.$$

where

$$X(t) = (X_1(t), X_2{}^{in}(t))$$
$$Z(t) = (Z_1(t), 0)$$
$$Y(t) = (Y_e(t), 0)$$
$$A = \begin{bmatrix} A_2 & A_3 \\ 0 & 0 \end{bmatrix}$$
$$F^{(\tau - t)} = \begin{bmatrix} 0 & 0 \\ F_3{}^{(\tau - t)} & 0 \end{bmatrix}$$

for every τ such that $t \leqslant \tau \leqslant t + \hat{\tau}$.

In order to solve this dynamic equation system (with lag $\hat{\tau}$), a set of initial conditions has been defined which specify $\hat{\tau}$ consecutive values of $X(t)$ and $Z(t)$.

	Energy supply system	Energy-related sectors	Capital investment	Vector $X^*(t)$
Energy-related sectors	A_1	A_2	A_3	$X_1(t)$
Capital investment	0	0	0	$X_2(t)$
WELMM	A_4	A_5	A_6	$X_3(t)$
Vector $X(t)$	$\bar{X}_e(t)$	$X_1(t)$	$X_2^{in}(t)$	

FIGURE 4 Structure of matrix A and of vectors $X^*(t)$ and $X(t)$.

	Energy supply system	Energy-related sectors	Capital investment
Energy-related sectors	F_1	0	0
Capital investment	F_2	F_3	0
WELMM	F_4	0	0
Vector $Z(t)$	$\bar{Z}_e(t)$	$Z_1(t)$	0

FIGURE 5 Structure of matrices $F^{(0)}, \ldots, F^{(\hat{\tau})}$ and of vector $Z(t)$.

The model calculates the economic impact of a given energy strategy for a given time interval (from t_0 to T); it does not take into account investment requirements for putting into operation new additional energy capacities after the year T. That is,

$$Z(t) = 0 \quad \text{if } t \geqslant T$$

$$X(t) = 0 \quad \text{if } t \geqslant T + 1$$

Thus, the model seeks to find all values of $X(t)$ for t less than $T + 1$ and for t greater than $t_0 - 1$. With these conditions, the model has the following format:

$$\begin{aligned}
X(T) &= AX(T) + Y(T) \\
X(T-1) &= AX(T-1) + F^{(0)}Z(T-1) + Y(T-1) \\
X(T-2) &= AX(T-2) + F^{(0)}Z(T-2) + F^{(1)}Z(T-1) + Y(T-2) \qquad (8) \\
&\vdots \\
X(t) &= AX(t) + F^{(0)}Z(t) + F^{(1)}Z(t+1) + \ldots + F^{(\hat{\tau})}Z(t_0 + \hat{\tau}) + Y(t_0) \\
&\vdots \\
X(t_0) &= AX(t_0) + F^{(0)}Z(t_0) + F^{(1)}Z(t_0 + 1) + \ldots + F^{(\hat{\tau})}Z(t_0 + \hat{\tau}) \\
&\quad + Y(t_0) \\
Z(T-1) &= \max \left[\min_{t_0 \leqslant \tau < T} (X(T) - X(\tau)); 0 \right] \\
Z(T-2) &= \max \left[\min_{t_0 \leqslant \tau < T-1} (X(T-1) - X(\tau)); 0 \right] \\
&\vdots \\
Z(t_0) &= \max \left[(X(t_0 + 1) - X(t_0)); 0 \right]
\end{aligned}$$

An iterative method – a modification of the Gauss–Seidel procedures – has been used to solve the equation system. The program proceeds from an initial "guess", the elements of which are set to zero. The program then defines a sequence of approximations which, in principle, converge to the solution.

Briefly, the algorithm is as follows: the Gauss–Seidel iteration procedure is used to solve the first subsystem

$$X(T) = AX(T) + Y(T)$$

Clearly the solution $X(T)$ to this subsystem does not depend on the other variables of system (8). The kth cycle of the iterative algorithm for solving the remaining part of equation system (8) constitutes one execution of the following two-step procedure.

Step 1. The Gauss–Seidel procedure is used to solve the equation system

$$X(T-1) = AX(T-1) + F^{(0)}Z(T-1) + Y(T-1)$$
$$\vdots$$
$$X(t_0) = AX(t_0) + F^{(0)}Z(t_0) + F^{(1)}Z(t_0+1) + \ldots + F^{(\hat{\tau})}Z(t_0+\hat{\tau}) + Y(1)$$

Vectors $Z(t)$, $(t = t_0, \ldots, T-1)$ are considered given from the $k-1$ cycle.

Step 2. Compute the values of vectors $Z(t)$ $(t = t_0, \ldots, T-1)$ by using the components of vectors $X(t)$ $(t = 1, 2, \ldots, T)$, obtained from step 1, and return to step 1.

A necessary condition for the convergence of this procedure is that matrix A be a so-called *convergent matrix*, i.e. that $\lim_{n\to\infty} A^m = 0$. Matrix A is convergent if all eigenvalues of A are less than 1 in absolute value; in that case, matrix $I-A$ is nonsingular, where matrix I denotes the identity matrix. Step 2 of the iterative algorithm is concerned primarily with solving linear equation systems of the type $X = AX + b$ where matrix A is the same for every time period $(t = 1, \ldots, T-1)$ and only vector b differs.

Although from the computational point of view it would seem more efficient to determine in advance the inverse of matrix $I-A$ and to use this for solving the equation system, the authors have not done so because the inversion procedure would increase the core requirements of the program by a factor of 2.

From the economical point of view, it is convenient to provide data for matrices $F^{(0)}, \ldots, F^{(\hat{\tau})}$ in the form of matrices $C, S_0, \ldots, S_{\hat{\tau}}$, where C is the matrix of expenditures coefficients for energy equipment per unit of capacity, and matrices $S_0, \ldots, S_{\hat{\tau}}$ are the coefficients of capital investment, material, and equipment distribution for each year of the construction period. The elements of matrices $F^{(0)}, \ldots, F^{(\hat{\tau})}$ are computed by multiplying the corresponding elements of matrices $C, S_0, \ldots, S_{\hat{\tau}}$.

4 DESCRIPTION OF THE COMPUTER PROGRAM

4.1 GENERAL CHARACTERISTICS

IMPACT was programmed in Fortran. Two versions of the model are available: the first version for use on the IBM 370; and the second one for use on the PDP 11/70 computer, which is operating at IIASA. For each of the versions there are three executable programs:

- IMDATA (input conversion and data modification)
- IMSETUP (model setup)
- IMSOLVE (solution algorithm)

The components of the IMPACT model system are shown in Figure 6.

All three programs run standalone under UNIX within the 56K word limit of the PDP 11/70. There are almost no limits on the model size of the PDP 11/70 because the core used for data storage depends only linearly on the size of the coefficient matrices.

IMPACT runs on the IBM 370 for the VM/370-CMS environment. Since the model operates almost entirely in-core, model size had to be limited to a maximum of 156 rows and 156 columns for matrices A, F^0, ..., $F^{(\hat{\tau})}$. Although the IBM 370 is less convenient than the PDP 11/70, the speed of execution of the IBM 370 is greater: a factor of some 30 exists between the time required to solve a problem on the IBM 370 as compared with the PDP 11/70, with a running time of 3 to 7 minutes on the IBM 370.

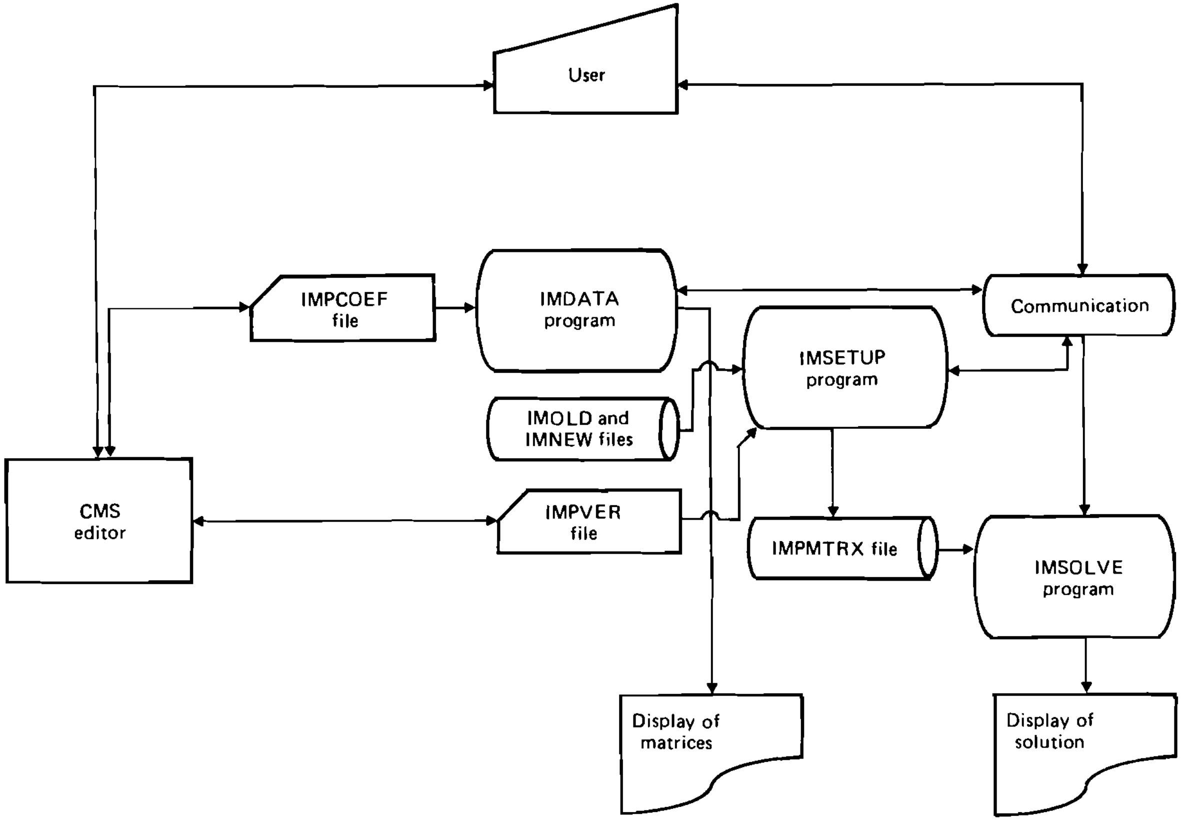

FIGURE 6 Components of the IMPACT model system.

4.2 THE IMPACT PROGRAM SYSTEM

4.2.1 Program IMDATA

Program IMDATA, which is the first component of the interactive IMPACT system for the VM/370-CMS environment, is designed to create and maintain data file IMOLD containing the coefficients of matrices A, C, $S_0, \ldots, S_{\hat{\tau}}$, where

- A is the matrix composed of matrices $A_1, A_2, \ldots, A_6$
- C is the matrix of expenditure coefficients for energy equipment per unit of capacity
- S_τ is the matrix of capital investment, material, and equipment distribution coefficients for each year τ of the construction period $0 \leqslant \tau \leqslant \hat{\tau}$

The sequence of operations executed in a program run is controlled by the user through interactive control commands and control variables. The procedures that can be initiated by the control commands are:

- INPUT (reads matrix data cards)
- MODIFY (reads correction data for modifying the matrices)
- LIST (displays the model matrices A, C, $S_0, \ldots, S_{\hat{\tau}}$ in various formats)

INPUT specifies matrix A and matrices C, $S_0, \ldots, S_{\hat{\tau}}$. INPUT reads the input data from file IMPCOEF, converts them into compact internal representation, and stores the converted data in file IMOLD. Only one IMOLD file can exist at a time; previously created IMOLD files must be renamed for future use before the current invocation of IMDATA. (For the organization of the file IMPCOEF and for the setup of the data deck for the INPUT procedure, see Section 5.1.2.)

The MODIFY procedure updates elements of matrices A, C, $S_0, \ldots, S_{\hat{\tau}}$ according to the input data given in file IMPCOEF. Corrections to elements of matrices A, C, $S_0, \ldots, S_{\hat{\tau}}$ are contained in file IMPCOEF. The setup of the data deck for the MODIFY procedure is given in Section 5.1.2. The MODIFY procedure uses data file IMOLD as the input file, and the updated file is written either back to the file IMOLD or to a new file IMNEW.

The LIST procedure displays on the standard printing device the entire matrices or selected parts thereof.

The control commands and the control variables for program IMDATA are discussed in Section 5.1.1.

Program IMDATA consists of one main program with seven subroutines; the subroutines are as follows:

Model input and modify level

INPUT (controls input and modifying level)
CUTA (inputs or modifies matrix A)
CUTF (inputs or modifies matrices C, $S_0, \ldots, S_{\hat{T}}$)
SUB (updates or creates model coefficients of file IMOLD)

Model output level

PRINT (controls printing matrices)
BER (prepares submatrices for printing)
LIST (displays submatrices in tabular form)

Figure 7 is a flow chart of the major subroutines and data files of program IMDATA.

4.2.1.1 MAIN PROGRAM

The main program opens input file IMPCOEF and data file IMOLD and calls subroutines INPUT and PRINT. Both the input and the output levels are controlled interactively. Program IMDATA has its own simple command language, consisting of seven control commands and eight control variables. A description of the control commands and control variables is given in Section 5.1.1.

4.2.1.2 SUBROUTINE INPUT

Subroutine INPUT manages the input and modify level. After all necessary parameter variables have been entered (see Section 5.1.1), the program reads file IMPCOEF. Subroutine PRODN reads product names; subroutines CUTA and CUTF read, respectively, A-MATRIX and F-MATRIX data cards. After the EOJ (end of data deck) card has been encountered, the program calls subroutine SUB to either update file IMOLD, if it exists, or create a new file, IMNEW.

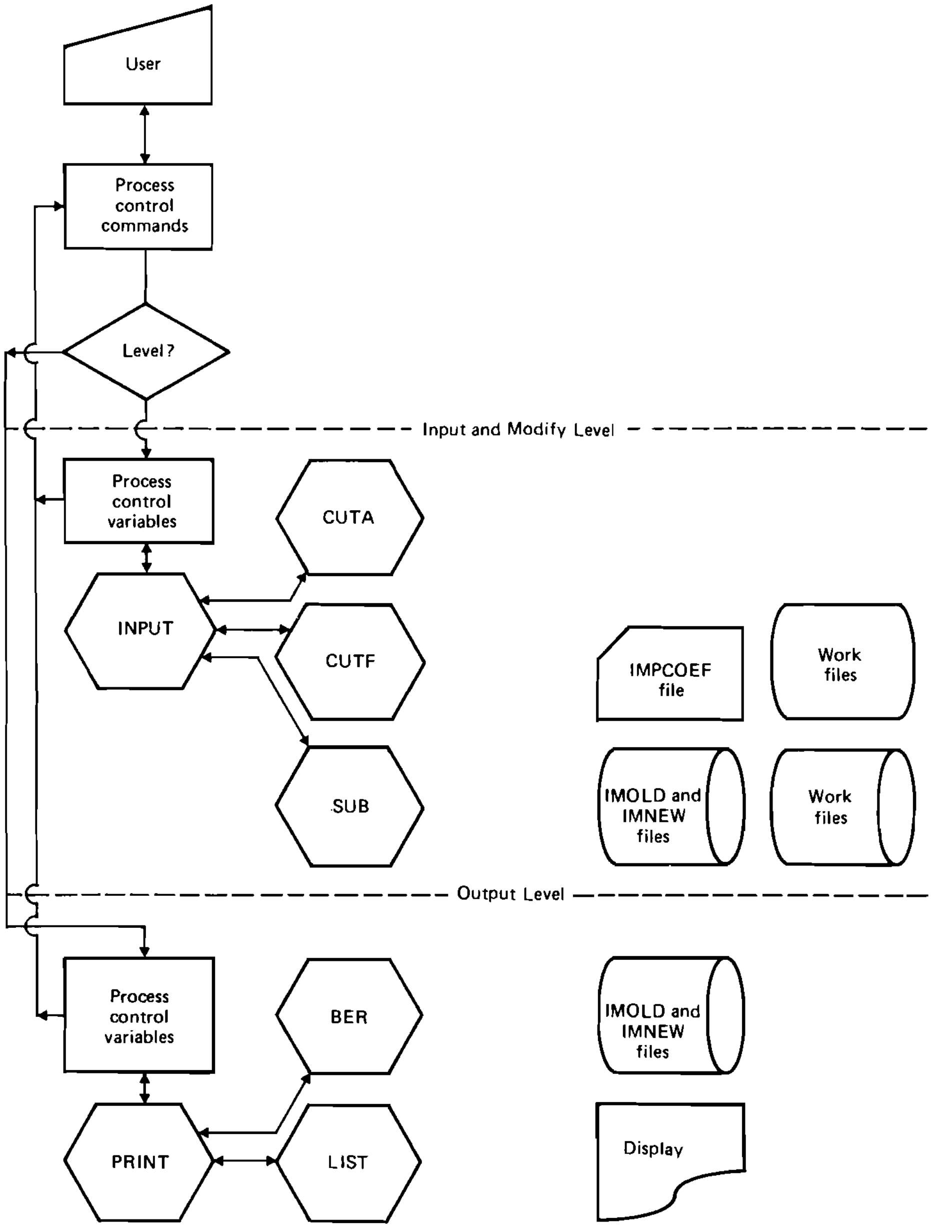

FIGURE 7 Program IMDATA.

4.2.1.3 SUBROUTINE PRINT

Subroutine PRINT manages the output level. After values of the control variables giving the name of the matrix and the index of the submatrix to be printed have been prompted, subroutine BER is called to prepare the submatrix for printing. The chosen submatrix is then displayed by subroutine LIST.

4.2.2 Program IMSETUP

Program IMSETUP, which is the second component of the interactive IMPACT system for the VM/370-CMS environment, is used to set up IMPACT for solution. Program IMSETUP creates the output file IMPMTRX from matrices A, $F^{(0)}$, ..., $F^{(\hat{\tau})}$, from the exogenous values for annual energy production ($\overline{X}_e$) and for additional capacities in the ESS ($\overline{Z}_e$), and from the model parameters, starting year (t_0), finishing year (T), and number of $F^{(\tau)}$ matrices, i.e., lag value $\hat{\tau}$ plus 1. The elements of matrix $F^{(\hat{\tau})}$ are computed by multiplying the corresponding elements of matrices C and $S_{\hat{\tau}}$.

Program IMSETUP uses as input the data file IMOLD (maintained by program IMDATA) and data file IMPVER which contains the exogenous variables $\overline{X}_e$ and $\overline{Z}_e$. Annual energy production ($\overline{X}_e$) is given for every nth year; program IMSETUP interpolates linearly the value for the other years. Additional capacities in the ESS ($\overline{Z}_e$) are given as the sum of capacity values for n consecutive years. A prescribed distribution function distributes these values over the other years. The format of file IMPVER, which should be prepared by the user, is given in Section 5.2.2.

The output of program IMSETUP is file IMPMTRX. Only one IMPMTRX file can exist at a time; previously created IMPMTRX files should be renamed. Execution time for IMSETUP is short.

Program IMSETUP consists of one main program with five subroutines; the subroutines are as follows:

Model coefficient setup level

SUB (controls setup level)
ACONV (sets up coefficients of matrix A)
FCONV (sets up coefficients of matrices $F^{(0)}, \ldots, F^{(\hat{\tau})}$)
SZET (auxiliary subroutine for subroutine FCONV)

Exogenous vector setup level

INTERP (interpolates annual values for vectors $\overline{X}_e(t)$ and $\overline{Z}_e(t)$)

Figure 8 is a flow chart of the major subroutines and files of program IMSETUP.

4.2.2.1 MAIN PROGRAM

The main program opens data files IMOLD and IMPVER, initializes the parameters, and calls subroutines ACONV, FCONV, and INTERP in order to set up file IMPMTRX. The setup is controlled interactively. Program IMSETUP has its own simple command language, consisting of about three control commands and six control variables. A description of the control commands and control variables is given in Section 5.2.1.

4.2.2.2 SUBROUTINE ACONV

Program IMSOLVE uses matrix A in the same format as it is stored in data file IMOLD; thus, the program's setup requires only slight modification to the storage format and its copying from the data base to file IMPMTRX. Changes in the coefficients of matrix A can be made by using the interactive command CHANGE. These modifications can be made only in file IMPMTRX.

4.2.2.3 SUBROUTINE FCONV

Subroutine FCONV computes the elements of matrices $F^{(0)}, \ldots, F^{(\hat{\tau})}$. The user submits the data for matrices $F^{(0)}$ in the form of matrices $C, S_0, \ldots, S_{\hat{\tau}}$, where C represents the matrix of expenditures for energy equipment per unit of capacity, and matrices $S_0, \ldots, S_{\hat{\tau}}$ represent the coefficients of capital investment, material, and equipment distribution for each year of the construction period. The elements of matrices $F^{(0)}$ are computed by multiplying the corresponding elements of matrices $C, S_0, \ldots, S_{\hat{\tau}}$. Temporary changes in the elements of matrices $C, S_0, \ldots, S_{\hat{\tau}}$ can be made interactively by using the control command CHANGE. These modifications can be made only in file IMPMTRX.

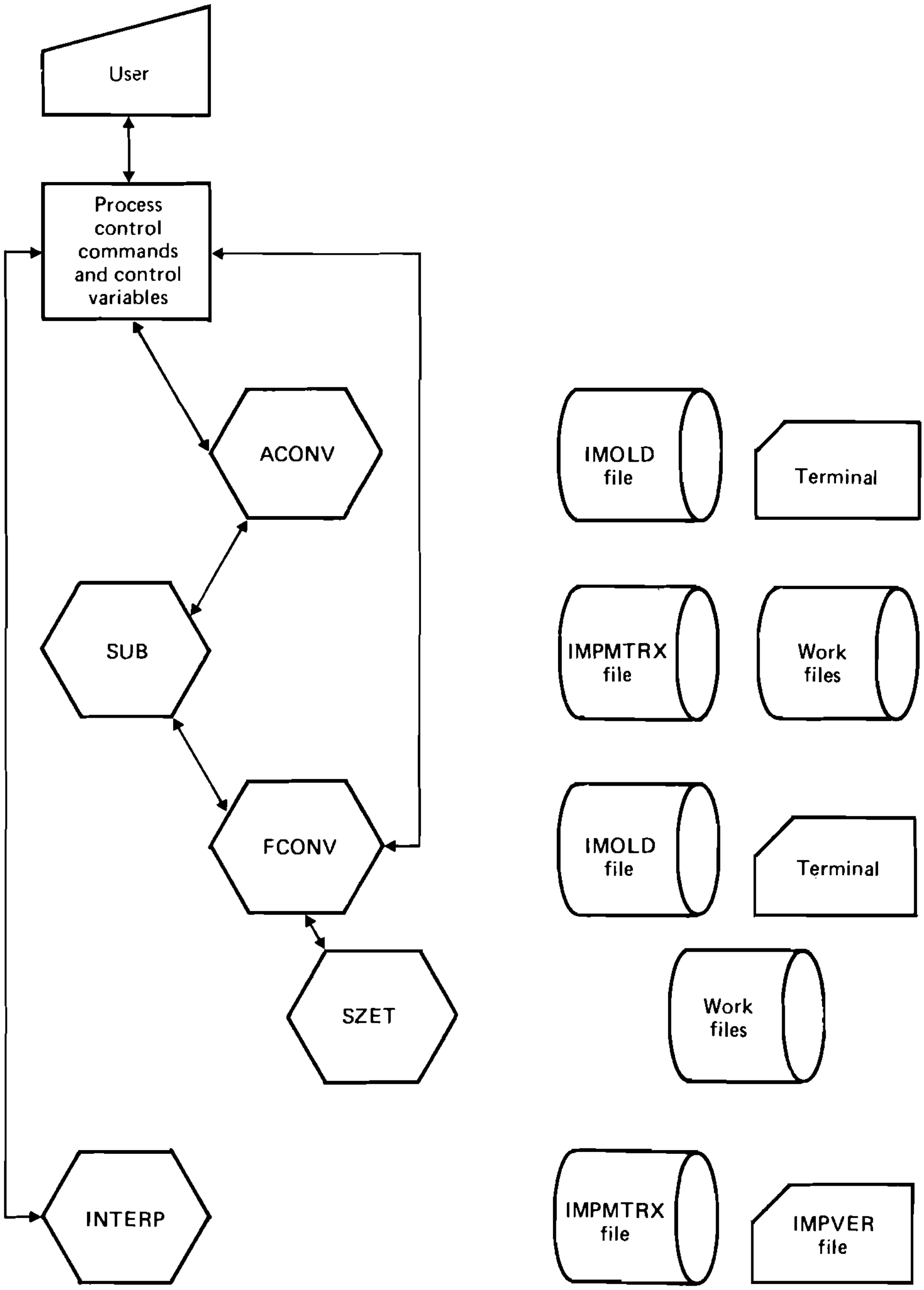

FIGURE 8 Program IMSETUP.

4.2.2.4 SUBROUTINE INTERP

Subroutine INTERP opens and reads file IMPVER which contains exogenous values for $\overline{X}_e$ and $\overline{Z}_e$. For the setup of the data deck of file IMPVER see Section 5.2.2. The values for $\overline{X}_e$ are given for every nth year; if the step size n is greater than 1, subroutine INTERP interpolates linearly the values for the other years. The values for $\overline{Z}_e$ are given as the sum of additional capacity values of n consecutive years. If step size n is greater than 1, subroutine INTERP distributes these values over the other years by a prescribed distribution function, which can be changed temporarily by the control command DISTR.

4.2.3 Program IMSOLVE

Program IMSOLVE, which is the third component of the interactive IMPACT system for the VM/370-CMS environment, is designed to solve IMPACT. Program IMSOLVE uses data file IMPMTRX produced by program IMSETUP.

The equations of the model are normalized for each of the endogenous variables. The two groups of endogenous variables are

$X(t)$, the vector of output of energy-related sectors in the year t
$Z(t)$, the vector of new additional capacities of energy-related sectors in the year t

The equation system consists of linear equations, which are normalized for vector $X(t)$, and of nonlinear equations, which are normalized for vector $Z(t)$. The linear equations are divided into a constant part and a function part. The constant part contains predetermined variables and parameters; the function part contains current endogenous variables and their coefficients.

The equation for time period t can be expressed as

$$X(t) = AX(t) + f(y(t))$$

where

$AX(t)$ is the function part of the equation
$f(y(t))$ is the constant part of the equation
$X(t)$ is the vector of an endogenous variable
$y(t)$ is the vector of predetermined variables consisting of exogenous vectors $\overline{X}_e(t)$ (annual energy production in the year t)

and $\overline{Z}_e(t)$ (required additional capacities in the ESS in the year t), and of endogenous vector $Z(t)$ whose values are computed by the nonlinear equations

The nonlinear equations normalized for vector $Z(t)$ have the following format at time period t:

$$Z(t) = \max \left[\min_{t_0 \leqslant \tau \leqslant t} (X(t+1) - X(\tau)); 0 \right]$$

where t_0 denotes the starting time period.

From the point of view of the algorithm, these nonlinear equations are not real equations requiring solution, since the values of vector $Z(t)$ are determined from the values of vector $X(t)$ which are computed by the linear equations.

The major iteration of the algorithm is composed of two phases:

Phase 1: Solving the linear equation system for every time period with predetermined values of vector $Z(t)$ (The Gauss–Seidel procedure, which solves the subsystem for a given time period t, is called a minor iteration.)

Phase 2: Computing the values of vector $Z(t)$ from the values of vector $X(t)$ obtained by phase 1

The major iteration process should be repeated until values of both vectors $X(t)$ and $Z(t)$ are found to a given accuracy.

Program IMSOLVE consists of a main program with 16 subroutines. The subroutines are as follows:

Model input level

OLV (inputs matrices A, $F^{(0)}, \ldots, F^{(\hat{\tau})}$)
ZNAM1 (inputs product names)
DEFX (inputs vectors $\overline{X}_e(t)$ and $\overline{Z}_e(t)$)

Algorithm

DINSOL (controls the major iteration)
ZB (sets up the right-hand side of the linear equation system at a given time period t)
SOLS (solves the linear subsystem)
ZN (computes new additional capacities for all sectors)
DEC (auxiliary procedure)

Model output level

PRISOL (generates the solution from files recorded by algorithm procedures)
FILW (auxiliary subroutine for subroutine PRISOL)
TABL (displays matrices in tabular form)
LISTX (auxiliary subroutine for subroutine TABL)
LISTAZ (auxiliary subroutine for subroutine TABL)
CUT (auxiliary subroutine for subroutine TABL)
BILD (plots the solution)
SOS (displays error messages)

Figure 9 is a flow chart of the major subroutines and files of program IMSOLVE; Figure 10 is a flow chart of the algorithm.

4.2.3.1 MAIN PROGRAM

The main program opens data file IMPMTRX and initializes the parameters required for the solution. Subroutines OLV, ZNAM1, and DEFX read, respectively, the coefficients of matrices A, $F^{(0)}$, ..., $F^{(\hat{\tau})}$, the product names, and the exogenous vectors $\overline{X}_e(t)$ and $\overline{Z}_e(t)$. The initial values of output $X(t)$ and of capacity $Z(t)$ are either read from file IMBASIS by subroutine DEFX (which could have been created by the previous run of program IMSOLVE containing the model solution) or they are set to zero. After all necessary parameters have been entered, the program calls subroutine DINSOL. Control is returned to the main program after a solution has been found to the specified accuracy or the limit on the number of major or minor iterations has been reached. At this time the user can make changes to the parameters and continue, or he can print the results and quit.

4.2.3.2 SUBROUTINE DINSOL

Subroutine DINSOL manages the major and minor iterations of the algorithm. A major iteration consists of solving a linear equation system for every time period and then computing new additional capacities for all sectors. During a minor iteration step, subroutine ZB is called to calculate the right-hand side of the linear equation system at a given time period. Thereafter program IMSOLVE calls subroutine SOLS. Control is

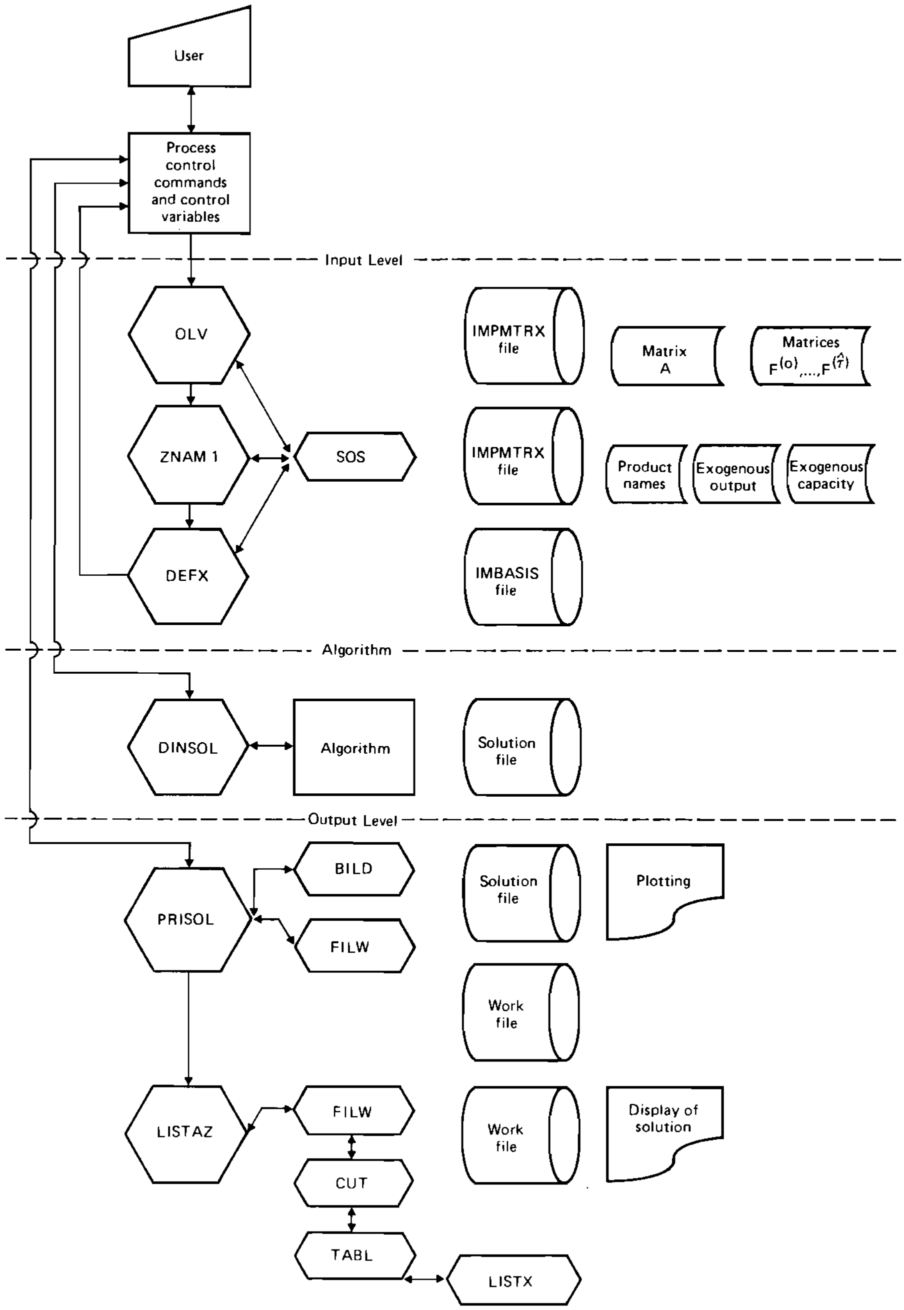

FIGURE 9 Program IMSOLVE.

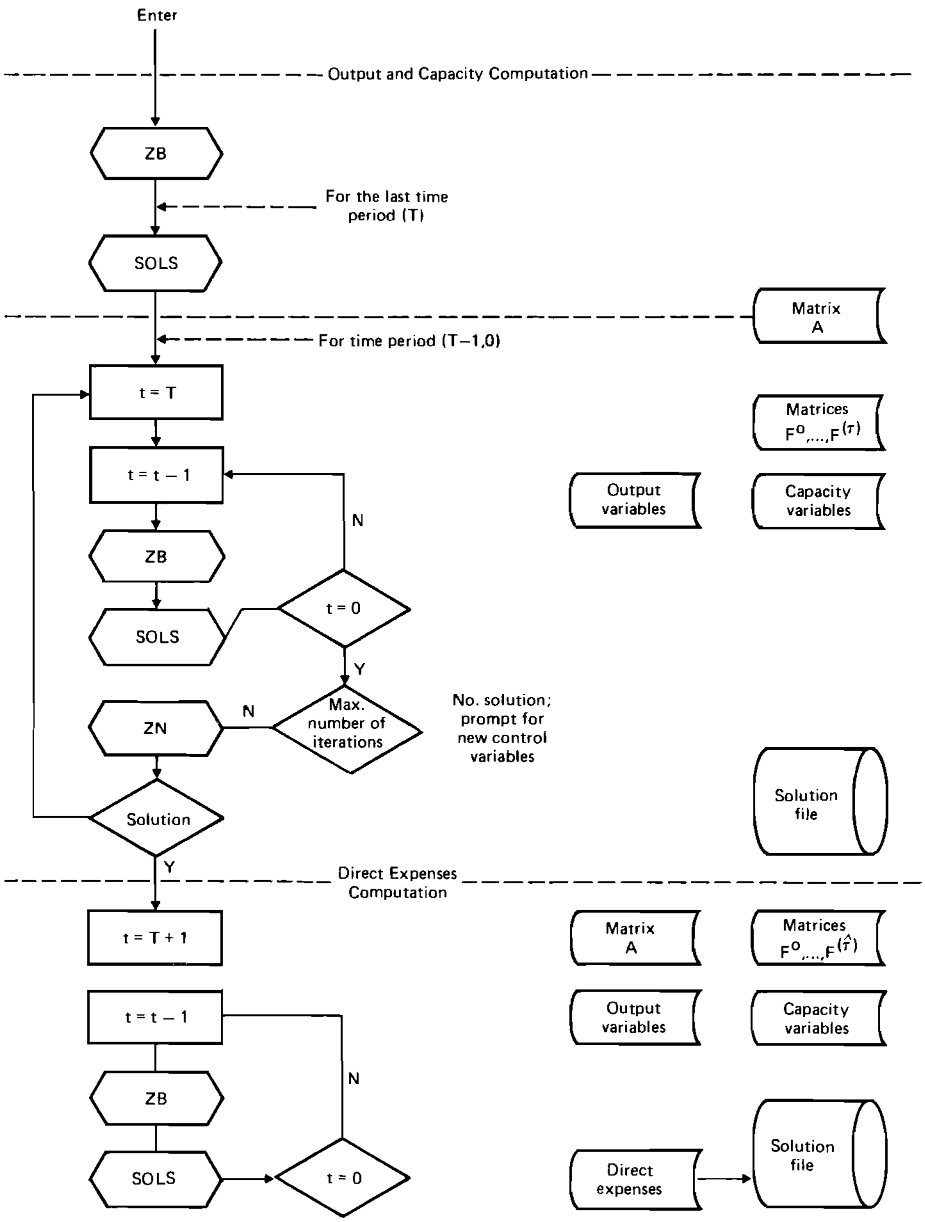

FIGURE 10 Algorithm of the IMPACT model system.

returned to subroutine DINSOL after a solution has been found to the linear equation system.

After the minor iteration step has been carried out for every time period, the program calls subroutine ZN to compute the values of new additional capacities for all sectors. After the solution to the model is found, the solution vectors are recorded and the direct expenses are calculated for every time period by calling subroutines ZB and SOLS.

4.2.3.3 SUBROUTINE ZB

Subroutine ZB is used to set up the right-hand side of the linear equation system at a given time period. This is computed from the following:

$\overline{X}_e(t)$, the vector of annual energy production in the year t
$\overline{Z}_e(t)$, the vector of required additional capacities in the ESS in the year t
$Z(t)$, the vector of new additional capacities in energy-related sectors in the year t
matrix $F_3{}^{(\tau - t)}$, whose coefficients are the capital investments in the year t to put into operation the capacities of the ESS and the energy-related sectors in the year τ

4.2.3.4 SUBROUTINE SOLS

Subroutine SOLS manages the solution to the linear equation system at a given time period t by means of the Gauss–Seidel procedure. If the model is solved for 75 periods, then subroutine SOLS is called 75 times during one major iteration step.

4.2.3.5 SUBROUTINE ZN

Subroutine ZN is called from subroutine DINSOL at the end of a major iteration step in order to compute new additional capacities for all sectors.

4.2.3.6 SUBROUTINE PRISOL

After a solution to the model system has been obtained, subroutine PRISOL is called upon to prepare it for direct printing; thereafter subroutine LISTAZ and/or subroutine BILD is called upon to display the solution in tabular form and/or in the form of plotted time functions.

5 USER GUIDE

5.1 RUNNING PROGRAM IMDATA

5.1.1 Prompting Sequence

At the beginning of each run, IMDATA prompts the user for the control commands and for the values of the control variables which hold the information needed to run the problem.

There are three types of control:

- Control commands, which regulate the execution of the tasks
- General information control variables, which contain the user's choice of model parameters – e.g., size of the matrices, lag value
- Parameter control variables, which are the parameters for the program

Each control variable has a default setting. The default setting, along with the description of its prompt, is given below. In order to specify the default value, the user hits the return key in response to the prompt. All prompts requiring a YES or a NO response have a default YES. The initial prompts appear at the user terminal in the order given below, and should be responded to as indicated.

5.1.1.1 CONTROL COMMANDS

ENTER THE LEVEL DESIRED. The level of input indicates whether to input new matrices or to update existing ones. The different levels and the corresponding control commands are given below.

Input Level. New coefficient matrices are read from file IMPCOEF and a new data file IMOLD is created. The control command for INPUT has the form INPUT [one or more options], where any one of the following options is possible:

- OLD: converted data are written to the file IMOLD rather than to file IMNEW.
- NEW: the updated matrices are directed to file IMNEW; but this option is default.
- ERR: in the presence of an input error during the input level, the data file IMOLD is not created. *Default*: the data file IMOLD is created if there are no fatal errors.
- NOPROM: default values are set for all parameter variables rather than prompt for their values. Prompting for general information control variables is not suppressed.

Modify Level. Existing data file IMOLD is revised. The control command for MODIFY has the form MODIFY [one or more options] where any one of the following options is possible:

- OLD: updated matrices are copied back to file IMOLD rather than copied to file IMNEW.
- NEW: the updated matrices are directed to file IMNEW; but this option is default.
- ERR: in the presence of an error during the modify level, the matrix updating is not carried out; the entire revise deck is processed in order to catch as many errors as possible. *Default*: the updated file IMOLD is produced if there are no fatal errors.
- NOPROM: default values are set for all parameter variables rather than prompt for their values. Prompting for general information control variables is not suppressed.

Output Level. The program displays on the standard printing device the entire matrices or selected parts thereof. The control command for OUTPUT has the form LIST [one or more options] where any one of the following options is possible:

- OLD: matrix coefficients are retrieved from file IMOLD rather than from file IMNEW.
- NEW: default.

NOPROM: default values are set for all parameter variables rather than prompt for their values.

5.1.1.2 GENERAL INFORMATION CONTROL VALUES

ENTER THE NAME OF THE INPUT DECK. The first card of the data deck contained in file IMPCOEF is always a NAME card, which gives a user-specified name to the data deck so that the data may be identified. After the user enters a name, the program compares it with the name given on the NAME card. An incorrect name results in a "failure to open file" error, and the prompt asking for the name of the data deck reappears. This prompt appears only at the input and modify levels.

DO YOU WISH TO USE INDEX INSTEAD OF NAME. This prompt appears only at the input and modify levels. The elements of the matrices in file IMPCOEF are identified either by name or by index. If names are used to identify matrix elements, then either file IMPCOEF has a PRODUCTS section defining the sequence of the product names, or file IMOLD contains a set of product names defined in a previous run. YES is typed if indices have been used in file IMPCOEF. NO is typed if names have been used. *Default*: YES.

ENTER THE ORDER OF MATRICES. This prompt specifies the order of matrices A, C, $S_0, \ldots, S_{\hat{T}}$. *Default*: use either the value of the order stored in file IMOLD, if it exists, or 156.

ENTER THE LAG VALUE. This defines the maximum number of S_i matrices stored in file IMOLD. *Default*: use either the lag value stored in file IMOLD, if it exists, or 6.

5.1.1.3 PARAMETER CONTROL VARIABLES

ENTER THE ZERO TOLERANCE. This specifies the tolerance below which a matrix element is set to zero. The tolerance value is 10^{-S}, where S is the number specified by the user. *Default*: 8.

ENTER THE NAME OF THE MATRIX TO BE PRINTED. This prompt, which appears only at the output level, specifies the name of the matrix to be printed. The possible choices are:

A for A matrix
C for C matrix
$S0$ for S_0 matrix

*S*1 for S_1 matrix
⋮
*S*6 for S_6 matrix

Default: A

ENTER THE INDEX OF THE SUBMATRIX TO BE PRINTED. This prompt, which appears only at the output level, determines the submatrices of the above specified matrix which should be printed. The indexing of the submatrices is shown in Figures 4 and 5. *Default*: all. (All submatrices of the above defined matrix will be printed.) After the level has been chosen by means of a control command and the control variables have been entered, the system prompts one of the following messages according to the chosen level:

AT LEVEL INPUT. NEXT?
AT LEVEL MODIFY. NEXT?
AT LEVEL LIST. NEXT?

The answer can be any one of the following options: EXEC, CONTINUE, RESTART, or STOP. By entering command EXEC, the system completes its work at the defined level and returns with one of the three prompts defined above. By entering command CONTINUE, the system remains at the same level, but restarts prompting for the parameter variables. By entering command RESTART, the system restarts with the prompt ENTER THE LEVEL DESIRED. By entering command STOP, the program closes all the files and finishes off.

5.1.2 Format of Data Cards and Organization of Data Deck for File IMPCOEF

The data file IMPCOEF for the INPUT and the MODIFY procedures contains four types of cards in all cases:

- A NAME card, which is always the first in a data deck
- Section-header cards, which specify the type of data that follows
- Data cards, which contain the actual data values
- An EOJ card, which is always the last card in a data deck

Comment cards, identified by a character *C* in column 1, may be inserted anywhere in a data deck.

5.1.2.1 NAME CARDS

The NAME card gives a user-specified name to the data decks so that the data may be identified. A NAME card has the following format:

Columns 1–4: NAME
Columns 9–16: name assigned by user

The name may contain from one to eight characters.

5.1.2.2 SECTION-HEADER CARDS

The data deck consists of data cards grouped according to the type of data they contain; a group of cards containing similar type of data is called a section. The first card of a section is always a section-header card identifying the type of data in that section. The types of data in a data deck are: PRODUCTS, A-MATRIX, and F-MATRIX. Section-header cards contain only one word specifying the type of data cards that follows. The first character must be in column 1.

5.1.2.3 DATA CARDS

Data cards are divided into "fields" – that is, consecutive card columns. The section-header card determines the field structure of the data cards. The three types of data cards are discussed below.

Product-Name Data Cards. PRODUCTS data cards specify the product names to be assigned to the rows and columns of the matrix. Because the ith row refers to the same product as that in the ith column, the product names should be defined only for the rows.

The format of a PRODUCTS data card is:

Columns 1–4: blanks
Columns 5–10: product names

In columns 5 to 10, blanks are considered characters and are not suppressed.

A-MATRIX Data Cards. A-MATRIX data cards define the actual value of the matrix elements in terms of row vectors. It is not necessary to specify the value if the coefficient is zero. The format of the A-MATRIX data card is shown in Table 3.

Field 1 gives the name or the index of the row that contains the elements specified in the fields that follow. Field 2 contains the name or the index of a column in which an element is to be entered. Field 3 contains the value of the element to be entered in the column and in the row of fields 1 and 2. Field 4 is optional and is used like field 2. Field 5 is optional and is used like field 3. Fields 6 to 9 are optional and are used like fields 2 and 3. All names in fields 1, 2, 4, 6, and 8 of the data card must consist of from one to six alphanumeric characters. If the fields give indices, then these should be numeric values. The matrix elements must be specified by rows – that is, all coefficients referring to the same row name (field 1) must be contiguous.

F-MATRIX Data Cards. F-MATRIX data cards specify the actual values of matrices C, S_0, ..., $S_{\hat{\tau}}$. The format of the F-MATRIX data card is shown in Table 4.

Field 2 identifies the name or the index of the row. Field 3 identifies the name or the index of the column of the matrices C, S_0, ..., $S_{\hat{\tau}-1}$, and $S_{\hat{\tau}}$ in which the elements specified in fields 4 to 7 are to be entered.

If the time lag τ is greater than 5, then the values of matrices C, S_0 ..., $S_{\hat{\tau}}$ should be defined by more than one card. The first card, which contains a blank field 1, defines the values of matrices C, S_0, S_1, S_2, ..., S_5; the continuous cards, which contain the character * in field 1, define the values of matrices S_6, ..., $S_{\hat{\tau}}$.

All matrix elements must be specified by rows – that is, when one element is given, all other elements in that row where the element of matrix C is other than zero must also be entered before another row can be mentioned. Zero entries should not be specified because they will be filled in automatically by the system.

5.1.2.4 EOJ CARDS

The EOJ card, which indicates the end of the data deck, has the following format:

Columns 1–3: EOJ

5.2 RUNNING PROGRAM IMSETUP

5.2.1 Prompting Sequence

At the beginning of each run, IMSETUP prompts the user for the control commands and for the values of the control variables which hold the information needed to run the problem.

TABLE 3 Format of *A*-MATRIX data cards for file IMPCOEF.

Field	Column	Content
1	5–10	Name or index
2	12–17	Name or index
3	18–25	Value
4	26–31	Name or index
5	32–39	Value
6	40–45	Name or index
7	46–53	Value
8	54–59	Name or index
9	60–67	Value

TABLE 4 Format of *F*-MATRIX data cards for file IMPCOEF.

Field	Column	Content
1	1	Blank or *
2	5–10	Name or index
3	12–17	Name or index
4	18–25	Value
5	26–33	Value
6	34–41	Value
7	42–49	Value
8	50–57	Value
9	58–65	Value
10	66–73	Value

There are three types of control:

- Control commands, which regulate the execution of the tasks
- General information control variables, which contain the user's choice of model parameters – e.g., size of matrices, lag value
- Parameter variables, which are the parameters for the program

Each control variable has a default setting. The default setting, along with the description of its prompt, is given below. In order to specify the default values, the user hits the return key in response to the prompt. All prompts requiring a YES or a NO response have a default YES. The initial prompts appear at the user terminal in the order shown below, and should be responded to as indicated.

5.2.1.1 CONTROL COMMANDS

Three commands are recognized by program IMSETUP. These can be entered only after the system has prompted the message ENTER CONTROL COMMANDS and the character * has appeared on the line following the above message. After a command has been issued from the terminal, the response is always the character *. If no additional control commands are to be entered, then the user hits the return key on a blank line, i.e., nothing is typed after the last carriage return.

The following control commands are accepted: CHANGE, DISTR, STOP.

The control command CHANGE is used if the user wishes to change the coefficient of the matrices A, C, S_0, ..., $S_{\hat{\tau}}$ for only one model run without changing the data in file IMOLD. The control command CHANGE has the form CHANGE [one or more options] where any one of the following options is possible:

- *A*: temporary changes are made in matrix A; *default*: no changes
- *C*: temporary changes are made in matrix C; *default*: no changes
- *SO*: temporary changes are made in matrix S_0; *default*: no changes
- *SN*: temporary changes are made in matrix S_N; symbol N represents any integer value in the range $[1,\hat{\tau}]$; *default*: no changes

If control command CHANGE was issued from the terminal, the program will ask to enter the modifications by prompting the message ENTER MODIFICATIONS FOR MATRIX "name", where name represents one of the matrix names used as one of the arguments of the control command CHANGE. These messages appear only after all prompts for values of the control variables have been answered. The modifications for matrices should be entered in the format of an A-MATRIX data card. In order to return to the program, the user hits the return key on a blank line, i.e., nothing is typed after the last carriage return. Then the program prompts for confirmation of the modification MODIFICATIONS CONFIRMED? YES/NO. NO is typed if the user wishes to repeat the modification phase.

The control command DISTR is used if the user wants to change the distribution function by which the sum of additional capacities is distributed over a given time interval. The command DISTR has the form DISTR [n] where the integer value n represents the value of the step size, i.e., the length of the distribution vector. *Default*: 5. The distribution vector is entered in response to the prompt ENTER DISTRIBUTION VECTOR. The actual values of the distribution are typed in as many lines as the dimension of the distribution vector. The values are entered in the first 12 positions of the line. After receiving the last value, the program prompts VALUES CONFIRMED? YES/NO. In the presence of any error in typing, the answer is NO, in which case the user can retype the whole distribution vector. In order to stop the execution of the program, the user commands STOP.

5.2.1.2 GENERAL INFORMATION CONTROL VARIABLES

ENTER THE NAME OF THE INPUT DECK. The first card of the data deck contained by file IMPVER is always a NAME card. The NAME card gives a user-specified name to the data deck so that the data may be identified. After entering a name chosen by the user, the program compares it with the name given on the NAME card. An incorrect name results in a "failure to open file" error, and the prompt asking for the name of the data deck reappears: DO YOU WISH TO USE INDEX INSTEAD OF NAME. The exogenous energy productions in file IMPVER are identified either by name or by index. YES is typed if the user has used indices in file IMPVER; NO is typed if the user has used names. *Default*: YES.

ENTER THE LAG VALUE. This defines the number of $F^{(\tau)}$ matrices for setting up the solution to the model.

ENTER THE STARTING YEAR. This defines the starting year of the time interval during which the model is solved. *Default*: 1975.

ENTER THE FINISHING YEAR. This defines the upper limit of the time interval during which the model is solved. *Default*: 2028.

5.2.1.3 PARAMETER CONTROL VARIABLES

ENTER THE ZERO TOLERANCE. This specifies the tolerance below which an element is set to zero. The tolerance value is 10^{-S}, where S is the number specified by the user. *Default*: 8.

5.2.2 Format of Data Cards and Organization of Data Deck for File IMPVER

The data file IMPVER for the SETUP procedure contains four types of cards:

- A NAME card, which is always the first in a data deck
- Section-header cards, which specify the type of data that follows

- Data cards, which contain the actual data values
- An EOJ card, which is always the last card in a data deck

Comment cards, identified by a character *C* in column 1, may be inserted anywhere in a data deck.

5.2.2.1 NAME CARDS

The NAME card gives a user-specified name to the data decks so that the data may be identified. It has the following format:

Columns 1–4: NAME
Columns 9–16: name assigned by user

The name may contain from one to eight characters.

5.2.2.2 SECTION-HEADER CARDS

The data deck consists of data cards grouped according to the type of data they contain; a group of cards containing similar type of data is called a section. The first card of a section is always a section-header card identifying the type of data in that section. The types of data in a data deck are: OUTPUT and CAPACITY. Section-header cards contain only one word specifying the type of data cards that follows. The first character must be in column 1.

5.2.2.3 DATA CARDS

Data cards are divided into ten fields. The type of data cards as defined by the section cards determines the content of each field, but all data cards follow the same general format. In this section, field 1 always refers to card columns 3 to 8; field 2 to card columns 10 to 13; and so on. The format of the data cards is shown in Table 5.

All the names contained in field 1 of the data cards must consist of from one to five alphanumeric and special characters. Eleven characters, which include a decimal point, define all numeric values appearing in fields 2 to 8. Specification of a sign is optional. If a sign is not specified, the plus sign (+) is implied. Values presented without a decimal point are interpreted as integers. Floating point format is also acceptable–that is, the Fortran "E" type format.

OUTPUT Data Cards. OUTPUT data cards specify the product name or the index of the energy production variables ($\overline{X}_e(t)$). Further, they define the actual value of the elements of these variables over the time interval $[T_1, T_2]$. Both years T_1 and T_2 are specified by control variables.

The actual values of elements of the variables are defined in terms of vectors; the length of these vectors is equal to the length of the time interval $[T_1, T_2]$.

The format of the OUTPUT data card is shown in Table 6.

Fields 5 to 8 are optional and are used only if the values defined by them are not zeros. All OUTPUT data cards referring to the same energy production must be contiguous, and the year on these cards should be increasing with respect to the order of the data cards. Energy production vectors with zero elements for every time period should not be specified, because they will be filled in automatically by the system. If the step size (field 3) is greater than 1, then the values for the other years are interpolated linearly.

CAPACITY Data Cards. CAPACITY data cards specify the values of the exogenous vector $\overline{Z}_e(t)$. The values of $\overline{Z}_e(t)$ are defined over the time interval $[T_1, T_2]$. Both years, T_1 and T_2, are defined by control variables.

The format of the CAPACITY data card is shown in Table 7.

Fields 5 to 8 are optional and are used only if the values defined by them are not zeros. All CAPACITY data cards referring to the same energy production must be contiguous and the year on these cards should be increasing with respect to the order of the data cards. Energy production with zero additional capacities for every year should not be specified, because they will be automatically filled in by the system. If the step

TABLE 5 Format of data cards for file IMPVER.

Field	Column	Content
1	3–8	Name or index
2	10–13	Integer value
3	15–16	Integer value
4	17–24	Value
5	25–32	Value
6	33–40	Value
7	41–48	Value
8	49–56	Value

TABLE 6 Format of OUTPUT data cards for file IMPVER.

Field	Content
1	Product name or index
2	Year
3	Step size
4	Energy production in year "field 2"
5	Energy production in year "field 2 plus the step size"
6	Energy production in year "field 2 plus two times the step size"
7	Energy production in year "field 2 plus three times the step size"
8	Energy production in year "field 2 plus four times the step size"

TABLE 7 Format of CAPACITY data cards for file IMPVER.

Field	Content
1	Product name or index
2	Year (t)
3	Step size (n)
4	Sum of additional capacities over time interval $[t - n, t - 1]$
5	Sum of additional capacities over time interval $[t, t + n - 1]$
6	Sum of additional capacities over time interval $[t + n, t + 2n - 1]$
7	Sum of additional capacities over time interval $[t + 2n, t + 2n, t + 3n - 1]$
8	Sum of additional capacities over time interval $[t + 3n, t + 4n - 1]$

size (field 3) is greater than 1, then the capacity sums will be distributed by a prescribed distribution function over the time interval.

5.2.2.4 EOJ CARD

The EOJ card, which indicates the end of the data deck, has the following format:

Columns 1–3: EOJ

5.3 RUNNING PROGRAM IMSOLVE

5.3.1 Prompting Sequence

At the beginning of each run, IMSOLVE prompts the user for the control commands and for the values of the control variables which hold the information needed to run the problem.

There are three types of control:

- Control commands, which regulate the execution of the tasks
- General information control variables, which contain the user's choice of model parameters – e.g., the name of the model
- Parameter control variables, which are the parameters for the program

Each control variable has a default setting. The default setting, along with the description of its prompt, is given below. In order to specify the default value, the user hits the return key in response to the prompt. All prompts requiring a YES or a NO response have a default YES. The initial prompts appear at the user terminal in the order below, and should be responded to as indicated.

5.3.1.1 CONTROL COMMANDS

Five commands are recognized by program IMSOLVE. The commands can be entered only after the system has prompted the message ENTER CONTROL COMMANDS and the character * has appeared on the line following the above message. After a command has been issued from the terminal, the response is always the character *. If no additional control commands are to be entered, then the user hits the return key on a blank line, i.e., nothing is typed after the last carriage return.

The following control commands are accepted: INPUT, SOLUTION, RESULTS, PRINT, STOP.

For the INPUT command, coefficient matrices and exogenous values will be read from file IMPMTRX. The control command for INPUT has the form INPUT [options] where any one of the following options is possible:

RESTORE: starting values for the output sector (X) and for the capacity vector (Z) will be initialized by the values read from file IMBASIS rather than by initializing them to zero.

NOPROM: default values are set for all parameter variables rather than prompt for their values. Prompting for general information control variables is not suppressed.

For the SOLUTION command, the major algorithm begins by computing the values of the output and the capacity vectors. The control command for SOLUTION has the form SOLUTION [NOPROM]. If option NOPROM is specified, default values are set for all parameter variables rather than prompt for their values.

For the RESULTS command, direct expenses are computed using the the current values of the output and the capacity vectors. The control command for RESULTS has the form RESULTS [NOPROM]. If option NOPROM is specified, default values are set for all parameter variables rather than prompt for their values.

For the PRINT command, the solution is displayed in tabular form and in the form of plotted time functions. The control command for PRINT has the form PRINT [options] where any one of the following options is possible:

PLOT: plotting is required.
NOPROM: default values are set for all parameter variables rather than prompt for their values.

The control command STOP brings the execution of the program to a close. The control command for STOP has the form STOP [SAVE]. If option SAVE is specified, the current values of output (X) and capacity (Z) vectors are stored in file IMBASIS.

5.3.1.2 GENERAL INFORMATION CONTROL VARIABLES

Prompts for general information control variables appear only after an INPUT control command has been issued.

ENTER THE NAME OF THE PROBLEM. In the setup level the name given on the NAME card of file IMPVER is stored in file IMPMTRX so that the model file may be identified. After the user has entered a name, the program compares this name with that stored in file IMPMTRX. An incorrect name results in a "failure to open file" error, and the prompt asking for the name of the model file reappears: DO YOU WISH A SHORT STATISTIC. If YES is typed, then a short statistic of the model parameter is displayed on the terminal.

5.3.1.3 PARAMETER CONTROL VARIABLES

ENTER THE NUMBER OF SIGNIFICANT DIGITS DESIRED AT THE FINAL SOLUTION. This determines the accuracy desired of the major algorithm. The algorithm terminates when the relative difference between two successive approximations is less than 10^{-S} for each element of output vector X, where S is the number of digits specified by the user. *Default*: 3.

ENTER THE MAXIMUM NUMBER OF MAJOR ITERATIONS. This sets an upper limit on the number of major iterations in the algorithm. Should the limit be exceeded before the specified accuracy has been reached, the user will be given the option to either terminate (STOP command) or specify a new maximum and continue. *Default*: 20.

ENTER THE NUMBER OF SIGNIFICANT DIGITS DESIRED AT THE SOLUTION OF THE SUBSYSTEM. This determines the accuracy desired for the Gauss–Seidel procedure. The Gauss–Seidel algorithm terminates when the difference between two successive approximations is less than 10^{-S} for each coordinate, where S is the number of digits specified by the user. *Default*: 5.

ENTER THE MAXIMUM NUMBER OF MINOR ITERATIONS. This sets an upper limit on the number of Gauss–Seidel iterations. Should the limit be exceeded before the specified accuracy has been reached, the user will be given the option to either terminate or specify a new maximum and continue.

ENTER THE ZERO TOLERANCE. This specifies the tolerance below which an element is set to zero; the tolerance is 10^{-S}, where S is the number specified by the user.

APPENDIXES

Appendix A

DATA BASE OF IMPACT

The selection of the energy sectors and of the energy-related sectors included in the model, as well as the completeness and the quality of the data, depend on the purposes of the model and the time horizon being considered. For example, the version of IMPACT that was used at the Siberian Power Institute for 15-year planning purposes consisted of about 50 energy activities and 60 energy-related activities. The IIASA version of the model, which is used to evaluate and compare long-range energy strategies for up to 50 years for 7 world regions, includes about 60 energy activities and about 30 activities for the energy sectors. The sectoral composition of IMPACT as it exists at IIASA is shown in Table A.1.

Each of the sectoral activities is characterized by the following indices:

- Input coefficient per unit of output (operation and maintenance requirements for some materials, equipment, and services)
- Capital coefficient (some material and equipment requirements per unit of new capacity or per dollar of capital investment)
- Incremental capital/output ratios (specific investment per unit of new capacity)
- WELMM coefficients (specific expenditures of water, energy, land, manpower, and some limited materials for operation and construction)
- Typical construction time
- Pattern of lags between construction expenditures and completion of the plant

In IMPACT, as in any energy-oriented model, the accuracy required of the data for energy activities must be higher than that required for the energy-related sectors. Therefore in the construction of the data base of IMPACT particular attention was paid to the energy part of the data base. Many different sources were analyzed and used, among them data received from the Bechtel Corporation in the U.S. and from the IIASA WELMM group.

TABLE A.1 Sectoral composition of IMPACT.

Number	Name	Abbreviation	Unit
Energy sectors			
1	Nonconventional oil	OIL 3	10^6 t
2	Nonexpensive oil	OIL 1	10^6 t
3	Intermediate oil	OIL 1A	10^6 t
4	Oil import	OILIMP	10^6 t
5	Z Z Z[a]		
6	Gas import	GASIMP	10^9 m^3
7	Oil pipelines	OILPIP	10^6 t
8	Oil shale mine	OILSHL	10^6 t
9	Oil shale retorting and upgrading	SHLOIL	10^6 t
10	Expensive oil	OIL 2	10^6 t
11	High-gasoline refinery	OILREF	10^6 t
12	Biogas	BIOGAS	GW(th)
13	Petroleum products: pipelines and marketing	PRPIP	10^6 t
14	Intermediate gas	GAS 1A	10^9 m^3
15	Expensive gas	GAS 2	10^9 m^3
16	Nonconventional gas	GAS	10^9 m^3
17	Gas pipelines	GASP	10^3 km
18	Cheap gas	GAS 1	10^9 m^3
19	Methanol from natural gas	MTHGAS	10^6 t(oe)
20	Natural gas stockpiles	STCKPL	10^9 m^3
21	Cheap coal	COAL 1	10^6 t(ce)
22	Intermediate coal	COAL 1A	10^6 t(ce)
23	Expensive coal	COAL 2	10^6 t(ce)
24	Z Z Z[a]		
25	Coal gasification (high Btu)	CLGAS	10^9 m^3
26	Methanol from coal	MTHCL	10^6 t(oe)
27	Coal liquefaction and refinery	CLLIQU	10^6 t
28	Coal transportation 1 (train) (coal unit train 10500 t)	CLTPNS	train
29	Coal import	CLIMP	10^6 t
30	Coal slurry pipeline	SLPYPE	10^3 km
31	Conventional power plants	CLPWPL	GW(e)
32	Nonexpensive uranium	U203–1	10^6 t ore
33	Expensive uranium	U203–2	10^6 t ore
34	Uranium mill	UMILL	10^3 t U_3O_8
35	Uranium conversion	UCONV	10^3 t UF_6
36	Uranium enrichment	UENRCH	10^3 t SWU
37	LWR fuel fabrication	LWRFL	10^3 t
38	Light water reactor	LWR	GW(e)

TABLE A.1 *Continued.*

Number	Name	Abbreviation	Unit
39	Z Z Z[a]		
40	LWR fuel reprocessing	LWRRPR	10^3 t
41	FBR fuel fabrication	FBRFL	10^3 t
42	Fast breeder reactor	FBR	GW(e)
43	FBR fuel reprocessing	FBRRPR	10^3 t
44	HTGR fuel fabrication and reprocessing	HTGRFL	10^3 t
45	High temperature reactor	HTGR	GW(e)
46	Hydrogen, thermochemical	H2THRM	10^9 m^3
47	Hydrogen pipeline	H2PYPE	10^3 km
48	Solar power plant (tower)	SOLARE	GW(e)
49	Pump storage	PUMPST	GW(e)
50	Geothermal power complex	GEOTH	GW(e)
51	Solar heating	SOLARH	GW/yr
52	Nuclear coal gasification	NCLGAS	10^9 m^3
53	Hydrogen, electrolytic	H2ELEC	10^9 m^3
54	Hydropower plants (expensive)	HYDRO2	GW(e)
55	Hydrogen liquefaction and storage	H2LIQU	10^6 t
56	Electricity transmission and distribution	ELTRNS	GW(e)
57	Hydropower plants (nonexpensive)	HYDRO1	GW(e)
58	Gas distribution	GASDST	10^9 m^3
59	Plants with sulphur dioxide removal	SO2REM	GW(e)
60	District heat	DISHT	GW(th)
Energy-related sectors			
61	Iron ores mining	IRNORE	10^6 US$
62	Primary iron and steel manufacturing	IR+STL	10^6 US$
63	Fabricated metal products	MTLPRD	10^6 US$
64	Nonferrous metal ore mining	NFEROR	10^6 US$
65	Nonferrous metals manufacturing	NFERMT	10^6 US$
66	Chemical products	CHEMPR	10^6 US$
67	Plastic and synthetic materials	PLSTIC	10^6 US$
68	Petroleum products	PTRLPR	10^6 US$
69	Stone, clay and glass products	BLDMTR	10^6 US$
70	Lumber and wood products	LMBWOD	10^6 US$
71	Miscellaneous materials	MSCLMT	10^6 US$
72	Total materials	TOTMT	10^6 US$
73	Engines and turbines	ENGIN	10^6 US$
74	Electrical equipment	ELEQP	10^6 US$
75	Mining equipment	MINEQP	10^6 US$

TABLE A.1 *Continued.*

Number	Name	Abbreviation	Unit
76	Oil field equipment	OILEQP	10^6 US$
77	Construction equipment and machineries	CNSEQP	10^6 US$
78	Material handling equipment	MHNDL	10^6 US$
79	Metalworking machineries	MWDRK	10^6 US$
80	Instrumental and control	INSTR	10^6 US$
81	Transportation equipment	TRNEQP	10^6 US$
82	Special industry equipment	SPCEQP	10^6 US$
83	General industry equipment	GENEQP	10^6 US$
84	Fabricated plate products	PLTPRD	10^6 US$
85	Miscellaneous equipment	MISEQP	10^6 US$
86	Total equipment	TOTEQP	10^6 US$
87	Z Z Z[a]		
88	Z Z Z[a]		
89	Export goods I	EXPRT1	10^9 US$
90	Export goods II	EXPRT2	10^9 US$
91	Construction in energy sectors	ENCNST	10^9 US$
92	Construction (energy-related)	CNSTRC	10^6 US$
93	Transport (energy-related)	TRNSP	10^6 US$
94	Maintenance and repair construction	M+REPR	10^6 US$
95	Trade	TRADE	10^6 US$
96	Communication	CMUNIC	10^6 US$
CAPITAL INVESTMENT			
Energy supply system (direct investment)			
97	Oil industry	OILINV	10^6 US$
98	Natural gas industry	GASINV	10^6 US$
99	Coal industry	CLINV	10^6 US$
100	Synthetic fuel industry	SYNTET	10^6 US$
101	Fuel transportation	FLTRNS	10^6 US$
102	Fossil fuel fired power plants	PWRPL	10^6 US$
103	LWR	LWRIN	10^6 US$
104	FBR	FBRIN	10^6 US$
105	Fuel cycle	FLCICL	10^6 US$
106	Solar, geothermal, and hydropower plants	SOLGEO	10^6 US$
107	Electricity transmission and distribution	ELTRNS	10^6 US$
108	Hydrogen	H2	10^6 US$
109	Other direct investments	OTHER	10^6 US$
110	Total direct investment (construction and owner cost)	TOTDIR	10^6 US$

TABLE A.1 *Continued.*

Number	Name	Abbreviation	Unit
111	Total construction cost	CONSTC	10^6 US$
Energy-related sectors (indirect investment)			
112	Ferrous metallurgy and mining industry	FERMET	10^6 US$
113	Nonferrous metallurgy	NFRMET	10^6 US$
114	Building materials industry	BLDMTR	10^6 US$
115	Chemical industry	CHEMIN	10^6 US$
116	Machinery	MACH	10^6 US$
117	Other industries	OTHIND	10^6 US$
118	Nonenergy transport	TRNSP	10^6 US$
119	Building industry	BLDIND	10^6 US$
120	Export (to compensate fuel import)	EXPORT	10^6 US$
121	Total indirect investment	TOTIND	10^6 US$
WELMM			
Manpower			
122	Oil and gas extraction	MOILGS	10^3 person yr/yr
123	Coal mining	MCOAL	10^3 person yr/yr
124	Synthetic fuel production	MSYNT	10^3 person yr/yr
125	Fuel transportation and distribution	MFLTRN	10^3 person yr/yr
126	Electricity transmission and distribution	MELTRN	10^3 person yr/yr
129	Power generating	PWRGNP	10^3 person yr/yr
130	Total direct operating manpower	TOTDOP	10^3 person yr/yr
131	Indirect operation manpower	INDOP	10^3 person yr/yr
132	Direct construction manpower	DIRCNS	10^3 person yr/yr
133	Indirect construction manpower	INDCNS	10^3 person yr/yr
140	Unskilled labor (direct operating requirements	UNSILL	10^3 person yr/yr
Land			
127	Right-of-way	LNDTEM	km^2
128	Fixed	LNDPRM	km^2
Materials			
134	Steel	FERMET	10^6 t
135	Cement	CEMENT	10^6 t
136	Lead	LEAD	10^3 t
137	Copper	COPPER	10^3 t
138	Aluminum	ALUMIN	10^3 t
139	Water	WATER	10^6 m^3

TABLE A.1 *Continued.*

Number	Name	Abbreviation	Unit
Energy (indirect)			
141	Electric power	ELPWR	10^9 kWh
142	Motive power	MTVPWR	10^{12} Btu
143	Process heat	PRCHT	10^{12} Btu
144	Water and space heat	W+SHT	10^{12} Btu
145	Coal	COAL	10^{12} Btu
146	Gaseous fuels	GASFL	10^{12} Btu
147	Liquid fuels	LIQUFL	10^{12} Btu
Air pollution emission factors			
148	Particulates	PRTCL	t
149	NO_x	NOX	t
150	SO_x	SOX	t
151	CO	CO	t
152	Z Z Z[a]		
153	Z Z Z[a]		
154	Z Z Z[a]		
155	Hydrocarbons	HYDROC	t

[a]Sectors reserved for future use.

For the IIASA model, capital costs of extracting oil, natural gas, and coal in different world regions were evaluated, taking into account current marginal capital costs, known resources and their distribution by price categories, anticipated time of exhaustion of these resources, and other factors. Some of the results of this evaluation are given in Table A.2. The generalized material structure of the capital investment in fuels extraction is shown in Table A.3. These data, received from the analyses of different sources, were used for estimating corresponding capital coefficients.

Capital costs and other economic indices for power plants and energy conversion technologies do not depend greatly on local conditions as do the indices for primary energy resources. Therefore they were considered identical for all world regions, and were based on perspective data for the U.S.

As to input/output and capital coefficients for energy-related sectors, the evaluations for the various world regions and for the perspective of 30 to 50 years are very rough and aggregated. It is impossible to obtain average regional indices by means of conventional procedures of aggregation, because of the lack of corresponding data for all countries of the region. Therefore for each region we selected one representative country, aggregated its coefficients, and then generalized them for all regions. Thus, for example, the U.S. was considered the representative country for North America, the Federal Republic of Germany for Western Europe, and India for Southeast Asia.

TABLE A.2 Fuel capital costs in IMPACT (10^6 US$).

Resource cost category[a]		Unit	Region: North America	South America	Western Europe	Middle East	South-East Asia and Africa
Oil	1	10^6 t	145	175	180	50	150
	2	10^6 t	275	250	275	150	250
	3	10^6 t	405	350	440	360	385
	4	10^6 t	550	550	550	-	550
Gas	1	10^9 m^3	130	100	200	30	120
	2	10^9 m^3	335	300	375	95	320
	3	10^9 m^3	540	500	540	300	520
	4	10^9 m^3	790	790	790	-	790
Coal	1	10^6 tce	30	65	70	-	35
	2	10^6 tce	70	90	140	-	70
	3	10^6 tce	150	180	210	-	110

[a]Cost categories cover fuel resources from present marginal production cost (category 1) to $25/boe (category 4).

TABLE A.3 Fuel capital costs in IMPACT (in percentage).

	Oil		Gas		Coal	
	Onshore	Offshore	Onshore	Offshore	Underground	Surface
Materials	*33*	*30*	*36*	*33*	*15*	*5*
Primary iron and steel	15	12	14	17	3	1
Nonferrous metals					1	0.5
Fabricated metal products	3	12	2	9.5	7.5	1.5
Glass, clay, and stone products	7	2	13	3	1	1
Chemical and allied products	6	3	7	3	1.5	0.2
Miscellaneous materials	2	1	-	0.5	2	0.8
Equipment	*31*	*41*	*18*	*31*	*49*	*61*
Electrical	1	1	1	1	3.5	1.5
Oil field	20	34	9	24	-	-
Mining	-	-	-	-	32	52
Transportation and material handling					7.5	4.2
Fabricated plate products	4	1	3	1	2.5	2
General industry	3	1	2	1	1	0.3
Miscellaneous	3	4	3	4	2.5	1
Manpower	*26*	*13*	*28*	*18.5*	*22*	*19*
Services and other constructor costs	*10*	*16*	*18*	*17.5*	*14*	*15*
Total constructor's costs	100	100	100	100	100	100
Owner's costs in relation to constructor's costs	51	96	51	94	76	29

Appendix B

TEST CASE

The purposes of this appendix are to show the format of the IMPACT model printout, and to assist the potential user of the computer program.

One of the scenarios that was analyzed at IIASA for studying problems of the transition to new energy sources in different world regions is the so-called coal scenario for the North American region. The scenario is characterized by a nuclear moratorium – that is, the stopping of the construction of new nuclear power plants after the year 1985 – and the absence of constraints on coal production.

The following printout of IMPACT (Tables B.1–B.9) includes input and output data. Capital coefficients and specific material and equipment expenditures to build and operate energy facilities were taken for North America mainly from the Bechtel Corporation data base (Carasco *et al.*, 1975; Hogle *et al.*, 1976). Data for the energy-related sectors were compiled and aggregated from input/output tables for the U.S., prepared for the years 1967, 1970, 1985, and 2000 by the Bureau of Economic Analysis (1975), by the Center for Advanced Computation of the University of Illinois (Bullard and Pilati, 1975), and by the Brookhaven National Laboratory (Hogle *et al.*, 1976). The capital coefficients were obtained from the Bureau of Economic Analysis (1975b), and from the Battelle Memorial Institute (1971).

TABLE B.1 Energy sector, output, physical units.[a]

	1980	1985	1990	1995	2000	2005	2010	2015	2020	2025	2030
OIL1	0.578E+03	0.520E+03	0.600E+03	0.645E+03	0.698E+03	0.426E+03	0.0	0.0	0.0	0.0	0.0
OIL1A	0.0	0.0	0.0	0.0	0.0	0.234E+03	0.443E+03	0.338E+03	0.270E+03	0.173E+03	0.0
OILIMP	0.231E+03	0.300E+03	0.210E+03	0.180E+03	0.900E+02	0.110E+03	0.360E+03	0.460E+03	0.480E+03	0.580E+03	0.680E+03
OILPIP*	0.693E+03	0.670E+03	0.705E+03	0.735E+03	0.743E+03	0.715E+03	0.623E+03	0.568E+03	0.510E+03	0.500E+03	0.505E+03
OIL2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.373E+02	0.165E+03
OILREF	0.724E+03	0.734E+03	0.744E+03	0.753E+03	0.764E+03	0.776E+03	0.796E+03	0.789E+03	0.810E+03	0.836E+03	0.895E+03
PRPIP*	0.724E+03	0.734E+03	0.744E+03	0.773E+03	0.784E+03	0.846E+03	0.896E+03	0.939E+03	0.990E+03	0.102E+04	0.104E+04
GAS2	0.0	0.0	0.0	0.0	0.0	0.0	0.599E+03	0.678E+03	0.611E+03	0.603E+03	0.564E+03
GASTRI*	0.149E+04	0.157E+04	0.180E+04	0.196E+04	0.206E+04	0.215E+04	0.291E+04	0.271E+04	0.245E+04	0.241E+04	0.226E+04
GAS1	0.743E+03	0.783E+03	0.899E+03	0.982E+03	0.103E+04	0.107E+04	0.255E+03	0.0	0.0	0.0	0.0
STCKPL*	0.0	0.0	0.0	0.0	0.0	0.0	0.599E+02	0.678E+02	0.611E+02	0.603E+02	0.564E+02
COAL1	0.742E+03	0.954E+03	0.111E+04	0.133E+04	0.159E+04	0.0	0.0	0.0	0.0	0.0	0.0
COAL1A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.186E+04	0.233E+04	0.286E+04	0.312E+04
CLLIQU	0.0	0.0	0.0	0.200E+02	0.200E+02	0.700E+02	0.100E+03	0.150E+03	0.180E+03	0.180E+03	0.150E+03
CLTRNS*	0.111E+04	0.143E+04	0.167E+04	0.199E+04	0.239E+04	0.0	0.0	0.278E+04	0.350E+04	0.429E+04	0.468E+04
SLPYPE*	0.148E+03	0.191E+03	0.223E+03	0.265E+03	0.318E+03	0.0	0.0	0.928E+03	0.117E+04	0.143E+04	0.156E+04
CLPWPL	0.580E+03	0.711E+03	0.843E+03	0.959E+03	0.103E+04	0.100E+04	0.870E+03	0.729E+03	0.535E+03	0.343E+03	0.178E+03
U303-1	0.196E+01	0.194E+01	0.190E+01	0.176E+01	0.132E+01	0.0	0.0	0.0	0.0	0.0	0.0
UMILL*	0.771E+01	0.757E+01	0.713E+01	0.627E+01	0.472E+01	0.0	0.0	0.0	0.0	0.0	0.0
UCONV*	0.907E+01	0.889E+01	0.836E+01	0.732E+01	0.551E+01	0.0	0.0	0.0	0.0	0.0	0.0
UENRCH*	0.499E+01	0.491E+01	0.468E+01	0.418E+01	0.315E+01	0.0	0.0	0.0	0.0	0.0	0.0
LWRFL*	0.151E+01	0.148E+01	0.139E+01	0.122E+01	0.918E+00	0.0	0.0	0.0	0.0	0.0	0.0
L W R	0.389E+02	0.386E+02	0.377E+02	0.348E+02	0.262E+02	0.0	0.0	0.0	0.0	0.0	0.0
LWRRPR*	0.101E+01	0.100E+01	0.979E+00	0.906E+00	0.682E+00	0.0	0.0	0.0	0.0	0.0	0.0
SOLARE	0.0	0.0	0.0	0.0	0.999E+01	0.400E+02	0.110E+03	0.110E+03	0.116E+03	0.138E+03	0.182E+03
PUMPST	0.0	0.0	0.0	0.0	0.500E+01	0.200E+02	0.550E+02	0.550E+02	0.579E+02	0.689E+02	0.909E+02
SOLARH	0.160E+02	0.280E+02	0.400E+02	0.530E+02	0.650E+02	0.770E+02	0.890E+02	0.990E+02	0.108E+03	0.115E+03	0.122E+03
ELTRNS*	0.729E+03	0.868E+03	0.101E+04	0.114E+04	0.126E+04	0.133E+04	0.146E+04	0.164E+04	0.175E+04	0.173E+04	0.183E+04
HPWPL1	0.110E+03	0.118E+03	0.127E+03	0.137E+03	0.147E+03	0.156E+03	0.165E+03	0.173E+03	0.181E+03	0.188E+03	0.194E+03
GASDST*	0.743E+03	0.783E+03	0.899E+03	0.982E+03	0.103E+04	0.107E+04	0.854E+03	0.678E+03	0.611E+03	0.603E+03	0.564E+03
S2ORMV	0.0	0.0	0.0	0.999E+01	0.400E+02	0.110E+03	0.260E+03	0.570E+03	0.862E+03	0.994E+03	0.118E+04

[a]Units are defined in Appendix A. Asterisk indicates endogenous variables which are evaluated in the model run.

TABLE B.2 Energy sector, capacity, physical units.[a]

	1980	1985	1990	1995	2000	2005	2010	2015	2020	2025	2030
OIL1	0.573E+01	0.133E+02	0.114E+02	0.101E+02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OIL1A	0.0	0.0	0.0	0.0	0.130E+02	0.116E+02	0.0	0.0	0.0	0.0	0.0
OILIMP	0.205E+02	0.0	0.0	0.0	0.0	0.0	0.305E+02	0.174E+02	0.340E+02	0.369E+02	0.438E+02
OILPIP*	0.156E+02	0.265E+02	0.265E+02	0.229E+02	0.161E+02	0.233E+01	0.713E+01	0.503E+01	0.129E+02	0.156E+02	0.523E+02
OIL2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.957E+01	0.710E+01	0.710E+01
OILREF	0.549E+01	0.802E+01	0.918E+01	0.106E+02	0.123E+02	0.615E+01	0.506E+01	0.927E+01	0.107E+02	0.141E+02	0.140E+02
PRPIP*	0.231E+02	0.233E+02	0.275E+02	0.247E+02	0.353E+02	0.346E+02	0.346E+02	0.376E+02	0.341E+02	0.353E+02	0.315E+02
GAS2	0.0	0.0	0.0	0.0	0.0	0.204E+02	0.196E+02	0.150E+02	0.150E+02	0.329E+02	0.329E+02
GASTR1*	0.594E+02	0.920E+02	0.856E+02	0.762E+02	0.774E+02	0.214E+03	0.0	0.258E+02	0.648E+02	0.391E+02	0.345E+02
GAS1	0.152E+02	0.198E+02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GAS1a	0.0	0.0	0.177E+02	0.120E+02	0.178E+02	0.0	0.0	0.0	0.0	0.0	0.0
STCKPL*	0.0	0.0	0.0	0.0	0.0	0.120E+02	0.332E+01	0.646E+00	0.162E+01	0.977E+00	0.863E+00
COAL1	0.180E+02	0.152E+02	0.180E+02	0.208E+02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COAL1A	0.0	0.0	0.0	0.0	0.0	0.0	0.208E+02	0.343E+02	0.459E+02	0.287E+02	0.213E+02
CLLIQU	0.0	0.0	0.100E+01	0.0	0.250E+01	0.171E+01	0.250E+01	0.151E+01	0.250E+01	0.500E+00	0.250E+01
CLTRNS*	0.960E+02	0.894E+02	0.112E+03	0.137E+03	0.0	0.0	0.0	0.224E+03	0.261E+03	0.202E+03	0.155E+03
SLPYPE*	0.128E+02	0.119E+02	0.150E+02	0.183E+02	0.0	0.0	0.0	0.747E+02	0.870E+02	0.673E+02	0.516E+02
CLPWPL	0.923E+01	0.974E+01	0.961E+01	0.824E+01	0.405E+01	0.266E+01	0.219E+01	0.0	0.0	0.0	0.0
U3O3-1	0.155E-01	0.150E-01	0.100E-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
UMILL*	0.213E+00	0.184E+00	0.250E-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
UCONV*	0.250E+00	0.216E+00	0.680E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
UENRCH*	0.138E+00	0.119E+00	0.637E-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LWRFL*	0.415E-01	0.358E-01	0.287E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
L W R	0.107E+01	0.939E+00	0.533E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LWRRPR*	0.279E-01	0.244E-01	0.139E-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOLARE	0.0	0.0	0.0	0.500E+00	0.150E+01	0.350E+01	0.0	0.300E+00	0.110E+01	0.270E+01	0.270E+01
PUMPST	0.0	0.0	0.0	0.999E+00	0.314E+01	0.758E+01	0.160E+01	0.220E+01	0.388E+01	0.640E+01	0.647E+01
SOLARH	0.287E+01	0.322E+01	0.377E+01	0.394E+01	0.429E+01	0.464E+01	0.459E+01	0.468E+01	0.455E+01	0.475E+01	0.515E+01
HPWPL2	0.0	0.0	0.0	0.0	0.0	0.0	0.100E+01	0.100E+01	0.100E+01	0.100E+01	0.100E+01
ELTRNS*	0.490E+02	0.531E+02	0.560E+02	0.572E+02	0.507E+02	0.647E+02	0.780E+02	0.706E+02	0.470E+02	0.699E+02	0.475E+02
HPWPL1	0.837E+00	0.900E+00	0.975E+00	0.100E+01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GASDST*	0.297E+02	0.460E+02	0.428E+02	0.381E+02	0.387E+02	0.0	0.0	0.0	0.0	0.977E+01	0.863E+01
S2ORMV	0.0	0.0	0.500E+00	0.150E+01	0.350E+01	0.750E+01	0.155E+02	0.146E+02	0.711E+01	0.110E+02	0.110E+02

[a]Units are defined in Appendix A. Asterisk indicates endogenous variables which are evaluated in the model run.

TABLE B.3 Energy-related sectors, direct expenses (10^6 US$).

MATERIALS	1980	1981-85	1986-90	1991-95	1996- 0	2001- 5	2006-10	2011-15	2016-20	2021-25	2026-30
IR+STL	0.411E+04	0.245E+05	0.301E+05	0.306E+05	0.321E+05	0.448E+05	0.517E+05	0.373E+05	0.324E+05	0.427E+05	0.447E+05
MTLPRD	0.630E+04	0.378E+05	0.461E+05	0.502E+05	0.558E+05	0.603E+05	0.645E+05	0.647E+05	0.885E+05	0.103E+06	0.115E+06
NFERMT	0.560E+04	0.299E+05	0.330E+05	0.351E+05	0.355E+05	0.373E+05	0.453E+05	0.504E+05	0.467E+05	0.439E+05	0.489E+05
CHEMPR	0.346E+04	0.210E+05	0.257E+05	0.280E+05	0.324E+05	0.278E+05	0.257E+05	0.302E+05	0.532E+05	0.618E+05	0.685E+05
PLSTIC	0.0	0.0	0.0	0.482E+02	0.206E+03	0.523E+03	0.432E+03	0.289E+02	0.143E+03	0.396E+03	0.594E+03
PTRLPR	0.653E+03	0.472E+04	0.546E+04	0.413E+04	0.422E+04	0.482E+04	0.607E+04	0.540E+04	0.486E+04	0.613E+04	0.783E+04
BLDMTR	0.143E+04	0.865E+04	0.102E+05	0.106E+05	0.136E+05	0.210E+05	0.224E+05	0.158E+05	0.167E+05	0.218E+05	0.281E+05
LMBWOD	0.136E+04	0.739E+04	0.837E+04	0.924E+04	0.987E+04	0.104E+05	0.125E+05	0.153E+05	0.171E+05	0.178E+05	0.193E+05
MSCLMT	0.617E+03	0.328E+04	0.438E+04	0.608E+04	0.644E+04	0.669E+04	0.587E+04	0.879E+04	0.122E+05	0.138E+05	0.158E+05
EQUIPMENT											
ENGIN	0.104E+04	0.848E+04	0.105E+05	0.133E+05	0.136E+05	0.167E+05	0.168E+05	0.157E+05	0.140E+05	0.160E+05	0.201E+05
ELEQP	0.673E+04	0.369E+05	0.411E+05	0.452E+05	0.483E+05	0.521E+05	0.587E+05	0.614E+05	0.638E+05	0.651E+05	0.743E+05
MINEQP	0.152E+04	0.946E+04	0.107E+05	0.126E+05	0.142E+05	0.509E+04	0.113E+04	0.126E+05	0.448E+05	0.547E+05	0.561E+05
OILEQP	0.187E+04	0.201E+05	0.274E+05	0.126E+05	0.129E+05	0.328E+05	0.557E+05	0.341E+05	0.319E+05	0.533E+05	0.747E+05
CNSEQP	0.136E+04	0.926E+04	0.103E+05	0.101E+05	0.943E+04	0.830E+04	0.946E+04	0.135E+05	0.121E+05	0.127E+05	0.120E+05
MHNDL	0.264E+03	0.182E+04	0.197E+04	0.228E+04	0.234E+04	0.152E+04	0.164E+04	0.364E+04	0.570E+04	0.640E+04	0.585E+04
MWORK	0.687E+00	0.459E+01	0.662E+01	0.949E+01	0.103E+02	0.194E+02	0.161E+02	0.167E+02	0.177E+02	0.205E+02	0.176E+02
INSTR	0.182E+04	0.100E+05	0.113E+05	0.133E+05	0.147E+05	0.182E+05	0.200E+05	0.187E+05	0.189E+05	0.204E+05	0.240E+05
TRNEQP	0.407E+04	0.230E+05	0.270E+05	0.319E+05	0.371E+05	0.181E+05	0.552E+04	0.193E+05	0.548E+05	0.657E+05	0.720E+05
SPCEQP	0.730E+02	0.368E+03	0.395E+03	0.443E+03	0.451E+03	0.603E+03	0.608E+03	0.662E+03	0.658E+03	0.691E+03	0.630E+03
GENEQP	0.241E+04	0.143E+05	0.174E+05	0.213E+05	0.229E+05	0.208E+05	0.184E+05	0.248E+05	0.444E+05	0.508E+05	0.543E+05
PLTPRD	0.226E+04	0.177E+05	0.205E+05	0.252E+05	0.267E+05	0.347E+05	0.341E+05	0.310E+05	0.267E+05	0.287E+05	0.349E+05
MISEQP	0.205E+04	0.147E+05	0.184E+05	0.150E+05	0.149E+05	0.200E+05	0.297E+05	0.260E+05	0.250E+05	0.310E+05	0.395E+05
OTHER SECT											
TRADE	0.129E+04	0.687E+04	0.761E+04	0.839E+04	0.910E+04	0.863E+04	0.827E+04	0.880E+04	0.110E+05	0.117E+05	0.123E+05

TABLE B.4 Energy-related sectors, output (10^6 US$).

MATERIALS	1980	1981-85	1986-90	1991-95	1996- 0	2001- 5	2006-10	2011-15	2016-20	2021-25	2026-30
IRNORE	0.600E+03	0.357E+04	0.417E+04	0.435E+04	0.473E+04	0.575E+04	0.606E+04	0.565E+04	0.643E+04	0.784E+04	0.847E+04
IR+STL	0.121E+05	0.721E+05	0.845E+05	0.879E+05	0.953E+05	0.117E+06	0.124E+06	0.114E+06	0.128E+06	0.157E+06	0.170E+06
MTLPRD	0.103E+05	0.595E+05	0.692E+05	0.753E+05	0.839E+05	0.915E+05	0.921E+05	0.994E+05	0.132E+06	0.154E+06	0.164E+06
NFEROR	0.107E+04	0.590E+04	0.655E+04	0.706E+04	0.746E+04	0.807E+04	0.885E+04	0.978E+04	0.103E+05	0.108E+05	0.116E+05
NFERMT	0.105E+05	0.580E+05	0.642E+05	0.694E+05	0.728E+05	0.788E+05	0.870E+05	0.968E+05	0.997E+05	0.103E+06	0.111E+06
CHEMPR	0.831E+04	0.489E+05	0.573E+05	0.617E+05	0.704E+05	0.684E+05	0.652E+05	0.750E+05	0.112E+06	0.131E+06	0.141E+06
PLSTIC	0.332E+04	0.186E+05	0.204E+05	0.216E+05	0.245E+05	0.268E+05	0.253E+05	0.297E+05	0.385E+05	0.451E+05	0.458E+05
PTRLPR	0.245E+04	0.151E+05	0.172E+05	0.166E+05	0.182E+05	0.197E+05	0.205E+05	0.219E+05	0.266E+05	0.315E+05	0.345E+05
HLDMTR	0.330E+04	0.182E+05	0.193E+05	0.206E+05	0.256E+05	0.361E+05	0.337E+05	0.311E+05	0.356E+05	0.437E+05	0.465E+05
LMBWOD	0.475E+04	0.267E+05	0.298E+05	0.321E+05	0.349E+05	0.388E+05	0.417E+05	0.490E+05	0.570E+05	0.633E+05	0.667E+05
MSCLMT	0.158E+05	0.930E+05	0.106E+06	0.112E+06	0.122E+06	0.138E+06	0.142E+06	0.158E+06	0.191E+06	0.223E+06	0.237E+06
TOTMT	0.724E+05	0.420E+06	0.479E+06	0.508E+06	0.560E+06	0.629E+06	0.647E+06	0.690E+06	0.837E+06	0.969E+06	0.104E+07
EQUIPMENT											
ENGIN	0.207E+04	0.147E+05	0.175E+05	0.208E+05	0.219E+05	0.250E+05	0.244E+05	0.250E+05	0.270E+05	0.316E+05	0.363E+05
ELEQP	0.113E+05	0.608E+05	0.660E+05	0.726E+05	0.788E+05	0.865E+05	0.905E+05	0.101E+06	0.109E+06	0.116E+06	0.123E+06
MINEQP	0.160E+04	0.989E+04	0.112E+05	0.132E+05	0.148E+05	0.567E+04	0.160E+04	0.133E+05	0.458E+05	0.558E+05	0.573E+05
OILEQP	0.187E+04	0.201E+05	0.274E+05	0.126E+05	0.129E+05	0.328E+05	0.557E+05	0.341E+05	0.319E+05	0.533E+05	0.747E+05
CNSEQP	0.221E+04	0.146E+05	0.168E+05	0.147E+05	0.162E+05	0.187E+05	0.161E+05	0.196E+05	0.216E+05	0.284E+05	0.233E+05
MHNDL	0.130E+04	0.734E+04	0.740E+04	0.721E+04	0.831E+04	0.954E+04	0.780E+04	0.123E+05	0.167E+05	0.204E+05	0.171E+05
MWORK	0.231E+04	0.112E+05	0.108E+05	0.113E+05	0.132E+05	0.171E+05	0.123E+05	0.182E+05	0.217E+05	0.260E+05	0.200E+05
INSTR	0.263E+04	0.142E+05	0.156E+05	0.180E+05	0.200E+05	0.246E+05	0.258E+05	0.260E+05	0.271E+05	0.297E+05	0.327E+05
TRNEQP	0.785E+04	0.435E+05	0.495E+05	0.565E+05	0.663E+05	0.438E+05	0.229E+05	0.452E+05	0.979E+05	0.118E+06	0.121E+06
SPCEQP	0.155E+04	0.679E+04	0.579E+04	0.695E+04	0.825E+04	0.880E+04	0.698E+04	0.131E+05	0.138E+05	0.153E+05	0.104E+05
GENEQP	0.472E+04	0.272E+05	0.311E+05	0.354E+05	0.389E+05	0.388E+05	0.340E+05	0.452E+05	0.715E+05	0.837E+05	0.850E+05
PLTPRD	0.393E+04	0.258E+05	0.283E+05	0.340E+05	0.369E+05	0.457E+05	0.418E+05	0.441E+05	0.433E+05	0.480E+05	0.504E+05
MISEQP	0.287E+04	0.188E+05	0.226E+05	0.194E+05	0.198E+05	0.260E+05	0.350E+05	0.329E+05	0.327E+05	0.403E+05	0.470E+05
TOTEQP	0.461E+05	0.275E+06	0.310E+06	0.323E+06	0.356E+06	0.383E+06	0.375E+06	0.430E+06	0.560E+06	0.666E+06	0.698E+06
OTHER SECT											
EXPRT1	0.197E+04	0.113E+05	0.127E+05	0.135E+05	0.150E+05	0.164E+05	0.160E+05	0.183E+05	0.234E+05	0.273E+05	0.284E+05
ENCNST	0.178E+05	0.112E+06	0.138E+06	0.159E+06	0.165E+06	0.208E+06	0.237E+06	0.227E+06	0.201E+06	0.227E+06	0.285E+06
CNSTRC	0.846E+04	0.351E+05	0.255E+05	0.305E+05	0.373E+05	0.501E+05	0.239E+05	0.623E+05	0.660E+05	0.747E+05	0.333E+05
TRNSP	0.371E+04	0.213E+05	0.238E+05	0.252E+05	0.279E+05	0.315E+05	0.312E+05	0.345E+05	0.419E+05	0.490E+05	0.508E+05
M+REPR	0.814E+03	0.470E+04	0.529E+04	0.559E+04	0.622E+04	0.687E+04	0.673E+04	0.742E+04	0.936E+04	0.110E+05	0.115E+05
TRADE	0.749E+04	0.420E+05	0.462E+05	0.494E+05	0.546E+05	0.597E+05	0.576E+05	0.664E+05	0.816E+05	0.939E+05	0.955E+05
CMUNIC	0.619E+03	0.351E+04	0.385E+04	0.411E+04	0.456E+04	0.514E+04	0.496E+04	0.572E+04	0.702E+04	0.818E+04	0.828E+04

TABLE B.5 Energy-related sectors, capacity (10^6 US$).

MATERIALS	1980	1981-85	1986-90	1991-95	1996- 0	2001- 5	2006-10	2011-15	2016-20	2021-25	2026-30
IRNORE	0.711E+02	0.256E+03	0.165E+03	0.180E+03	0.302E+03	0.518E+03	0.146E+03	0.757E+02	0.430E+03	0.533E+03	0.228E+03
IR+STL	0.147E+04	0.522E+04	0.333E+04	0.357E+04	0.616E+04	0.111E+05	0.306E+04	0.657E+03	0.867E+04	0.108E+05	0.475E+04
MTLPRD	0.105E+04	0.400E+04	0.320E+04	0.373E+04	0.450E+04	0.373E+04	0.224E+04	0.970E+04	0.776E+04	0.841E+04	0.532E+04
NFEROR	0.850E+02	0.316E+03	0.299E+03	0.295E+03	0.301E+03	0.487E+03	0.358E+03	0.508E+03	0.207E+03	0.731E+03	0.138E+03
NFERMT	0.828E+03	0.303E+04	0.296E+04	0.284E+04	0.284E+04	0.481E+04	0.394E+04	0.459E+04	0.160E+04	0.707E+04	0.122E+04
CHEMPR	0.816E+03	0.332E+04	0.257E+04	0.338E+04	0.332E+04	0.838E+03	0.129E+04	0.108E+05	0.663E+04	0.723E+04	0.492E+04
PLSTIC	0.188E+03	0.102E+04	0.789E+03	0.111E+04	0.139E+04	0.990E+03	0.253E+03	0.306E+04	0.233E+04	0.219E+04	0.125E+04
PTRLPR	0.355E+03	0.102E+04	0.664E+03	0.530E+03	0.953E+03	0.105E+04	0.571E+03	0.160E+04	0.147E+04	0.210E+04	0.103E+04
BLDMTR	0.151E+03	0.967E+03	0.777E+03	0.118E+04	0.269E+04	0.342E+04	0.0	0.0	0.217E+04	0.358E+04	0.111E+04
LMBWOD	0.425E+03	0.148E+04	0.139E+04	0.137E+04	0.187E+04	0.192E+04	0.198E+04	0.347E+04	0.265E+04	0.321E+04	0.214E+04
MSCLMT	0.193E+04	0.557E+04	0.470E+04	0.453E+04	0.746E+04	0.724E+04	0.357E+04	0.129E+05	0.105E+05	0.130E+05	0.754E+04
TOTMT	0.735E+04	0.261E+05	0.204E+05	0.231E+05	0.318E+05	0.358E+05	0.126E+05	0.515E+05	0.446E+05	0.589E+05	0.290E+05
EQUIPMENT											
ENGIN	0.750E+03	0.926E+03	0.134E+04	0.109E+04	0.109E+04	0.171E+04	0.688E+03	0.145E+04	0.859E+03	0.294E+04	0.126E+04
ELEQP	0.613E+03	0.293E+04	0.301E+04	0.354E+04	0.350E+04	0.517E+04	0.232E+04	0.606E+04	0.277E+04	0.777E+04	0.119E+04
MINEQP	0.315E+03	0.551E+03	0.697E+03	0.837E+03	0.501E+03	0.0	0.0	0.654E+04	0.356E+04	0.235E+04	0.195E+04
OILEQP	0.125E+04	0.300E+04	0.326E+04	0.0	0.0	0.704E+04	0.642E+04	0.0	0.0	0.585E+04	0.844E+04
CNSEQP	0.399E+03	0.799E+03	0.138E+04	0.0	0.709E+03	0.130E+04	0.396E+03	0.120E+04	0.982E+03	0.209E+04	0.0
MHNDL	0.475E+02	0.421E+03	0.260E+03	0.153E+03	0.453E+03	0.804E+03	0.502E+02	0.129E+04	0.123E+04	0.122E+04	0.0
MWORK	0.0	0.649E+03	0.318E+03	0.453E+03	0.913E+03	0.158E+04	0.0	0.960E+03	0.202E+04	0.163E+04	0.0
INSTR	0.153E+03	0.661E+03	0.904E+03	0.883E+03	0.139E+04	0.204E+04	0.257E+02	0.104E+04	0.851E+03	0.240E+04	0.565E+03
TRNEQP	0.438E+03	0.241E+04	0.276E+04	0.348E+04	0.304E+04	0.0	0.0	0.985E+04	0.636E+04	0.591E+04	0.377E+04
SPCEQP	0.0	0.301E+03	0.0	0.600E+03	0.316E+03	0.493E+03	0.446E+03	0.164E+04	0.281E+03	0.530E+03	0.0
GENEQP	0.412E+03	0.154E+04	0.187E+04	0.144E+04	0.222E+04	0.505E+03	0.657E+03	0.769E+04	0.437E+04	0.348E+04	0.314E+04
PLTPRD	0.106E+04	0.113E+04	0.210E+04	0.163E+04	0.313E+04	0.286E+04	0.673E+03	0.183E+04	0.799E+03	0.352E+04	0.207E+04
MISEQP	0.537E+03	0.155E+04	0.115E+04	0.0	0.929E+03	0.335E+04	0.221E+04	0.595E+03	0.124E+04	0.304E+04	0.299E+04
TOTEQP	0.564E+04	0.160E+05	0.126E+05	0.143E+05	0.190E+05	0.152E+05	0.103E+05	0.439E+05	0.317E+05	0.388E+05	0.201E+05
OTHER SECT											
EXPRT1	0.177E+03	0.660E+03	0.534E+03	0.635E+03	0.847E+03	0.576E+03	0.377E+03	0.178E+04	0.133E+04	0.142E+04	0.863E+03
ENCNST	0.435E+04	0.678E+04	0.146E+05	0.362E+04	0.133E+05	0.216E+05	0.548E+04	0.474E+04	0.408E+02	0.269E+05	0.110E+05
CNSTRC	0.0	0.186E+04	0.0	0.215E+04	0.167E+04	0.680E+04	0.0	0.632E+04	0.561E+04	0.381E+04	0.0
TRNSP	0.325E+03	0.124E+04	0.957E+03	0.117E+04	0.164E+04	0.157E+04	0.572E+03	0.271E+04	0.236E+04	0.271E+04	0.137E+04
M+REPR	0.753E+02	0.282E+03	0.211E+03	0.267E+03	0.351E+03	0.317E+03	0.131E+03	0.631E+03	0.540E+03	0.625E+03	0.318E+03
TRADE	0.543E+03	0.224E+04	0.191E+04	0.231E+04	0.299E+04	0.203E+04	0.137E+04	0.586E+04	0.444E+04	0.450E+04	0.268E+04
CMUNIC	0.472E+02	0.189E+03	0.153E+03	0.197E+03	0.268E+03	0.211E+03	0.964E+02	0.507E+03	0.391E+03	0.412E+03	0.214E+03

TABLE B.6 Capital investment (10^6 US$).

DIRECT	1980	1981-85	1986-90	1991-95	1996- 0	2001- 5	2006-10	2011-15	2016-20	2021-25	2026-30
OILINV	0.216E+04	0.207E+05	0.338E+05	0.314E+05	0.338E+05	0.590E+05	0.431E+05	0.580E+04	0.179E+05	0.624E+05	0.532E+05
GASINV	0.209E+04	0.270E+05	0.304E+05	0.0	0.0	0.328E+05	0.146E+06	0.134E+06	0.108E+06	0.137E+06	0.237E+06
CLINV	0.922E+03	0.696E+04	0.633E+04	0.745E+04	0.651E+04	0.0	0.339E+04	0.188E+05	0.294E+05	0.339E+05	0.217E+05
SYNTET	0.0	0.0	0.348E+05	0.978E+05	0.887E+05	0.903E+05	0.175E+05	0.181E+05	0.164E+05	0.145E+05	0.113E+05
FLTRNS	0.665E+04	0.401E+05	0.443E+05	0.423E+05	0.394E+05	0.413E+05	0.405E+05	0.519E+05	0.352E+05	0.419E+05	0.364E+05
PWRPL	0.946E+04	0.610E+05	0.646E+05	0.672E+05	0.645E+05	0.665E+05	0.107E+06	0.144E+06	0.106E+06	0.745E+05	0.968E+05
LWR	0.523E+03	0.238E+04	0.148E+04	0.297E+03	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FLCICL	0.583E+02	0.255E+03	0.138E+03	0.279E+02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOLGEO	0.998E+03	0.684E+04	0.736E+04	0.144E+05	0.337E+05	0.706E+05	0.619E+05	0.167E+05	0.321E+05	0.663E+05	0.930E+05
ELTRNS	0.116E+05	0.610E+05	0.653E+05	0.681E+05	0.665E+05	0.655E+05	0.827E+05	0.930E+05	0.777E+05	0.647E+05	0.771E+05
OTHER	0.696E+04	0.373E+05	0.423E+05	0.484E+05	0.532E+05	0.616E+05	0.615E+05	0.591E+05	0.608E+05	0.627E+05	0.669E+05
TOTDIR	0.554E+05	0.355E+06	0.444E+06	0.495E+06	0.509E+06	0.654E+06	0.775E+06	0.736E+06	0.661E+06	0.776E+06	0.971E+06
CONSTC	0.414E+05	0.263E+06	0.331E+06	0.377E+06	0.386E+06	0.488E+06	0.563E+06	0.541E+06	0.483E+06	0.558E+06	0.694E+06

INDIRECT											
FERMET	0.342E+04	0.170E+05	0.107E+05	0.125E+05	0.188E+05	0.300E+05	0.378E+04	0.186E+05	0.328E+05	0.342E+05	0.134E+05
NFRMET	0.762E+03	0.366E+04	0.352E+04	0.336E+04	0.311E+04	0.543E+04	0.537E+04	0.454E+04	0.241E+04	0.809E+04	0.901E+03
BLDMTR	0.324E+03	0.107E+04	0.897E+03	0.199E+04	0.332E+04	0.378E+04	0.0	0.662E+03	0.304E+04	0.392E+04	0.109E+04
CHEMIN	0.232E+04	0.908E+04	0.554E+04	0.910E+04	0.668E+04	0.659E+04	0.646E+04	0.243E+05	0.186E+05	0.180E+05	0.111E+05
MACH	0.329E+04	0.117E+05	0.957E+04	0.953E+04	0.116E+05	0.178E+05	0.992E+04	0.240E+05	0.215E+05	0.259E+05	0.114E+05
OTHIND	0.345E+04	0.138E+05	0.104E+05	0.123E+05	0.164E+05	0.164E+05	0.127E+05	0.279E+05	0.273E+05	0.292E+05	0.156E+05
TRNSP	0.944E+03	0.386E+04	0.280E+04	0.380E+04	0.451E+04	0.494E+04	0.333E+04	0.694E+04	0.794E+04	0.779E+04	0.361E+04
BLDIND	0.708E+03	0.374E+04	0.499E+04	0.215E+04	0.563E+04	0.110E+05	0.266E+04	0.164E+04	0.461E+04	0.125E+05	0.226E+04
TOTIND	0.152E+05	0.639E+05	0.484E+05	0.547E+05	0.701E+05	0.961E+05	0.443E+05	0.109E+06	0.118E+06	0.140E+06	0.594E+05

TABLE B.7 Capital investment (10^6 US$).

DIRECT	1980	1981-85	1986-90	1991-95	1996- 0	2001- 5	2006-10	2011-15	2016-20	2021-25	2026-30
OILINV	0.522E+01	0.786E+01	0.102E+02	0.832E+01	0.874E+01	0.121E+02	0.765E+01	0.107E+01	0.369E+01	0.112E+02	0.768E+01
GASINV	0.505E+01	0.102E+02	0.919E+01	0.0	0.0	0.673E+01	0.259E+02	0.248E+02	0.223E+02	0.245E+02	0.342E+02
CLINV	0.223E+01	0.264E+01	0.191E+01	0.197E+01	0.169E+01	0.0	0.601E+00	0.348E+01	0.608E+01	0.608E+01	0.313E+01
SYNTET	0.0	0.0	0.105E+02	0.259E+02	0.230E+02	0.185E+02	0.310E+01	0.334E+01	0.340E+01	0.261E+01	0.162E+01
FLTRNS	0.160E+02	0.152E+02	0.134E+02	0.112E+02	0.102E+02	0.848E+01	0.719E+01	0.960E+01	0.728E+01	0.751E+01	0.525E+01
PWRPL	0.228E+02	0.232E+02	0.195E+02	0.178E+02	0.167E+02	0.136E+02	0.190E+02	0.265E+02	0.219E+02	0.133E+02	0.140E+02
LWR	0.126E+01	0.902E+00	0.448E+00	0.787E-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FLCICL	0.141E+00	0.966E-01	0.416E-01	0.738E-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOLGEO	0.241E+01	0.260E+01	0.223E+01	0.381E+01	0.872E+01	0.145E+02	0.110E+02	0.309E+01	0.665E+01	0.119E+02	0.134E+02
ELTRNS	0.280E+02	0.231E+02	0.198E+02	0.180E+02	0.172E+02	0.134E+02	0.147E+02	0.172E+02	0.161E+02	0.116E+02	0.111E+02
OTHER	0.168E+02	0.142E+02	0.128E+02	0.128E+02	0.138E+02	0.126E+02	0.109E+02	0.109E+02	0.126E+02	0.113E+02	0.965E+01
TOTDIR	0.134E+03	0.135E+03	0.134E+03	0.131E+03	0.132E+03	0.134E+03	0.138E+03	0.136E+03	0.137E+03	0.139E+03	0.140E+03
CONSTC	0.100E+03	0.100E+03	0.100E+03	0.100E+03	0.100E+03	0.100E+03	0.100E+03	0.100E+03	0.100E+03	0.100E+03	0.100E+03
INDIRECT											
FERMET	0.224E+02	0.266E+02	0.221E+02	0.228E+02	0.268E+02	0.313E+02	0.854E+01	0.171E+02	0.277E+02	0.245E+02	0.226E+02
NFRMET	0.500E+01	0.573E+01	0.728E+01	0.613E+01	0.444E+01	0.565E+01	0.121E+02	0.418E+01	0.204E+01	0.580E+01	0.152E+01
BLDMTR	0.212E+01	0.168E+01	0.185E+01	0.364E+01	0.474E+01	0.393E+01	0.0	0.610E+00	0.257E+01	0.281E+01	0.183E+01
CHEMIN	0.152E+02	0.142E+02	0.114E+02	0.166E+02	0.954E+01	0.686E+01	0.146E+02	0.224E+02	0.157E+02	0.129E+02	0.186E+02
MACH	0.216E+02	0.182E+02	0.198E+02	0.174E+02	0.166E+02	0.185E+02	0.224E+02	0.221E+02	0.182E+02	0.186E+02	0.193E+02
OTHIND	0.226E+02	0.216E+02	0.215E+02	0.226E+02	0.235E+02	0.171E+02	0.287E+02	0.257E+02	0.231E+02	0.209E+02	0.263E+02
TRNSP	0.619E+01	0.604E+01	0.579E+01	0.693E+01	0.644E+01	0.514E+01	0.753E+01	0.639E+01	0.671E+01	0.558E+01	0.607E+01
BLDIND	0.465E+01	0.584E+01	0.103E+02	0.392E+01	0.804E+01	0.115E+02	0.602E+01	0.151E+01	0.390E+01	0.896E+01	0.381E+01
TOTIND	0.100E+03	0.100E+03	0.100E+03	0.100E+03	0.100E+03	0.100E+03	0.100E+03	0.100E+03	0.100E+03	0.100E+03	0.100E+03

TABLE B.8 WELMM requirements (person yr/yr).

MATERIALS	1980	1981-85	1986-90	1991-95	1996- 0	2001- 5	2006-10	2011-15	2016-20	2021-25	2026-30
FERMET	0.755E+01	0.579E+02	0.755E+02	0.716E+02	0.790E+02	0.137E+03	0.136E+03	0.702E+02	0.721E+02	0.133E+03	0.144E+03
CEMENT	0.280E+01	0.266E+02	0.356E+02	0.244E+02	0.258E+02	0.309E+02	0.392E+02	0.172E+02	0.196E+02	0.335E+02	0.432E+02
COPPER	0.197E+03	0.120E+04	0.145E+04	0.207E+04	0.195E+04	0.232E+04	0.208E+04	0.192E+04	0.170E+04	0.181E+04	0.209E+04
ALUMIN	0.516E+03	0.275E+04	0.299E+04	0.325E+04	0.318E+04	0.348E+04	0.410E+04	0.416E+04	0.348E+04	0.337E+04	0.373E+04
WATER	0.192E+05	0.108E+06	0.126E+06	0.142E+06	0.157E+06	0.165E+06	0.171E+06	0.190E+06	0.220E+06	0.231E+06	0.238E+06
ENERGY(IND)											
ELPWR	0.446E+03	0.245E+04	0.266E+04	0.280E+04	0.299E+04	0.310E+04	0.317E+04	0.354E+04	0.446E+04	0.504E+04	0.537E+04
MTVPWR	0.245E+02	0.138E+03	0.152E+03	0.161E+03	0.179E+03	0.204E+03	0.197E+03	0.225E+03	0.271E+03	0.316E+03	0.319E+03
PROCHT	0.119E+04	0.689E+04	0.783E+04	0.828E+04	0.928E+04	0.104E+05	0.105E+05	0.110E+05	0.137E+05	0.161E+05	0.172E+05
W+SHT	0.436E+02	0.252E+03	0.283E+03	0.299E+03	0.329E+03	0.373E+03	0.378E+03	0.414E+03	0.500E+03	0.582E+03	0.610E+03
COAL	0.493E+03	0.290E+04	0.335E+04	0.351E+04	0.387E+04	0.456E+04	0.470E+04	0.461E+04	0.547E+04	0.655E+04	0.704E+04
GASFL	0.128E+04	0.744E+04	0.845E+04	0.894E+04	0.100E+05	0.112E+05	0.112E+05	0.119E+05	0.149E+05	0.175E+05	0.187E+05
LIQUFL	0.961E+03	0.546E+04	0.610E+04	0.651E+04	0.735E+04	0.801E+04	0.767E+04	0.870E+04	0.113E+05	0.132E+05	0.136E+05
PRTCL	0.289E+04	0.167E+05	0.190E+05	0.204E+05	0.227E+05	0.240E+05	0.830E+05	0.133E+06	0.146E+06	0.148E+06	0.147E+06
NOX	0.126E+05	0.670E+05	0.757E+05	0.853E+05	0.937E+05	0.849E+05	0.768E+05	0.812E+05	0.149E+06	0.167E+06	0.179E+06
SOX	0.722E+04	0.414E+05	0.481E+05	0.539E+05	0.615E+05	0.457E+05	0.327E+05	0.550E+05	0.159E+06	0.192E+06	0.215E+06
CO	0.802E+03	0.456E+04	0.511E+04	0.535E+04	0.587E+04	0.644E+04	0.656E+04	0.710E+04	0.824E+04	0.941E+04	0.980E+04
DEATH	0.647E+02	0.350E+03	0.389E+03	0.430E+03	0.474E+03	0.276E+03	0.150E+03	0.272E+03	0.810E+03	0.965E+03	0.108E+04
INJURY	0.332E+04	0.170E+05	0.182E+05	0.196E+05	0.206E+05	0.191E+05	0.182E+05	0.180E+05	0.228E+05	0.239E+05	0.249E+05
MANDLS	0.317E+06	0.170E+07	0.188E+07	0.207E+07	0.229E+07	0.159E+07	0.109E+07	0.173E+07	0.496E+07	0.590E+07	0.658E+07
HYDROC	0.129E+04	0.710E+04	0.766E+04	0.765E+04	0.812E+04	0.844E+04	0.855E+04	0.902E+04	0.104E+05	0.117E+05	0.124E+05

TABLE B.9 Average manpower requirements (person yr/yr).

	1980	1981-85	1986-90	1991-95	1996- 0	2001- 5	2006-10	2011-15	2016-20	2021-25	2026-30
TOTDOP	0.114E+04	0.102E+04	0.117E+04	0.134E+04	0.150E+04	0.125E+04	0.977E+03	0.104E+04	0.172E+04	0.190E+04	0.201E+04
INDOP	0.260E+04	0.249E+04	0.281E+04	0.294E+04	0.326E+04	0.366E+04	0.366E+04	0.401E+04	0.500E+04	0.589E+04	0.619E+04
DIRCNS	0.186E+03	0.232E+03	0.289E+03	0.411E+03	0.380E+03	0.425E+03	0.372E+03	0.419E+03	0.349E+03	0.315E+03	0.370E+03
INDCNS	0.423E+02	0.289E+02	0.209E+02	0.251E+02	0.307E+02	0.412E+02	0.197E+02	0.512E+02	0.542E+02	0.614E+02	0.274E+02

REFERENCES

Battelle Memorial Institute (1971) An ex-Ante Capital Matrix for the United States, 1970–1975. Columbus, Ohio.

Beaujean, J.-M., and J.-P. Charpentier, eds. (1976) A Review of Energy Models. No. 3, December 1976. Special Issue on Soviet Models. RR-76-18. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Bullard, C.W., and D.A. Pilati (1975) Direct and Indirect Requirements for a Project Independence Scenario. CAC Document No. 178. Urbana: Center for Advanced Computation, University of Illinois.

Bureau of Economic Analysis (1975a) Summary Input–Output Tables of the U.S. Economy: 1968, 1969, 1970. Staff Paper No. 27. Washington, D.C.: U.S. Department of Commerce.

Bureau of Economic Analysis (1975b) A Study of Fixed Capital Requirements of the US Business Economy 1971–1980. PB-248690. Washington, D.C.: U.S. Department of Commerce.

Carasco, M. *et al.* (1975) The Energy Supply Planning Model, Final Project Report. San Francisco, California: Bechtel Corporation.

Hogle, J.K. *et al.* (1976) Manpower, Materials, and Capital Costs for Energy-Related Facilities. Upton, New York: Brookhaven National Laboratory.

Kononov, Yu. (1976) Modeling of the Influence of Energy Development of Different Branches of the National Economy. RR-76-11. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Kononov, Yu., ed. (1972) Problems of Optimization and Management in Energy Systems, The Investigation of External Relations. Irkutsk: Siberian Power Institute, Siberian Branch of the USSR Academy of Sciences (in Russian).

Kononov, Yu., and A. Makarov, eds. (1975) Problems of the Influence of Energy Production Development on Other Sectors of the National Economy. Irkutsk: Siberian Power Institute, Siberian Branch of the USSR Academy of Sciences (in Russian).

Rogner, H.-H. (1977) A Macroeconomic Model of the Potential GNP (MACRO). Internal paper. Laxenburg, Austria: International Institute for Applied Systems Analysis.

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