

A MODEL APPROACH FOR EVALUATING  
THE IMPACT ON THE ECONOMY OF  
DIFFERENT ENERGY STRATEGIES

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\* Views or opinions expressed in this paper do not necessarily reflect those of the National Member Organizations supporting the Institute or of the Institute itself.

INTRODUCTION

The energy sector is one of the key sectors of the economy. This fact was made obvious to a broad public by the so called oil crisis of 1973. On the one hand energy is a production factor which is necessary for all production processes within the economy, and on the other hand the energy industry itself is a main contributor to the gross national product as well as a main consumer of investment products within the industry. This can be seen from the figures given in Table I.

Table I: The economic position of the energy sector in the FRG (figures of 1972)

	Contribution to GNP				Employees			Investments			
	10 <sup>9</sup>	DM	%	%	10 <sup>6</sup>	%	%	10 <sup>9</sup>	DM	%	%
Energy sector	44.1		13	5	0.5	6	2	12.7		25	6
Industry	335.1		100		8.9	100		50.1		100	
Total economy	844.3			100	26.6		100	217.4			100

During the worldwide efforts to analyze the energy problems and to develop future energy policies, it turned out that the question of the feasibility of implementing the energy policies is of great importance. This is true in terms of the requirements for economic resources associated with the construction and operation of the energy supply and transportation facilities needed to implement these energy policies.

Addressing that question, the Bechtel Corporation has developed a model [1] to calculate the direct resource requirements for different future energy programs. At the Siberian Power Institute a model was developed by Yu. Kononov to determine the influence of different energy strategies on the different branches of the economy [2]. The SPI model will be available at

IIASA.

This paper now describes a model approach mainly based on the Input-Output-Technique to evaluate the overall requirements of different energy policies in terms of output of different economy sectors, capital, manpower and material.

The model is designed to help answer the following questions:

- What are and how different are the overall requirements of various energy strategies?
- What are the overall impacts of investment needs of different energy technologies or energy programs on the output of different branches of the economy?
- How will the operational requirements of different energy technologies and energy programs influence the structure of the economy?
- What overall (direct and indirect) capital, manpower, and materials are going to be needed and when?

The following description starts with the explanation of an approach to investigate the overall economic requirements for constructing and operating an energy technology. In order to put into operation a single or a set of energy technologies a static approach to calculate the overall output of the different branches of the economy is described. Thereafter a method to evaluate the time-phased impact (investment and operational requirements) of different energy strategies on the economy is explained, some remarks follow on the "import assessment problem" implied in the comparison of the economic requirements of different energy policies.

#### 1. Economic Requirements of Energy Technologies (Static Approach)

In this section a method will be described to investigate the overall requirements of different energy technologies from the economy, without taking into account the timing of these requirements.

The questions which should be answered are:

- What are the direct and indirect requirements (inputs from other economy sectors, capital, manpower, and material) for constructing an energy facility or an energy supply system?

- What output is necessary from the other economy sectors to operate this facility or an energy supply system?

Concerning these two questions, the approach distinguishes between the investment and the operational requirements.

### 1.1 Total investment requirements

Let us assume that the investment necessary to construct an energy facility is  $I$ . To construct this facility, products from different sectors of the economy are required. The breakdown of the investment  $I$  to the deliveries of the different economy sectors is described by

$$I = \sum_{i=1}^n I_i \quad , \quad (1)$$

where:

$I_i = 1, \dots, n$  investment deliveries of the sectors ( $i = 1, \dots, n$ ) of the economy which make up the investment  $I$ ,

or with  $F_i$  the fraction of material and equipment expenditures per unit of investment  $I$  from the sector  $i$  of the economy

$$I = \sum_{i=1}^n F_i \cdot I \quad . \quad (2)$$

In matrix notation the investment deliveries from the different sectors of the economy are

$$\bar{I} = \bar{F} \cdot I \quad . \quad (3)$$

Using the basic identities of an input-output table (and relying therefore on the basic assumptions and hypotheses of the I-0-technique), the gross output of sector  $i$  of the economy is given by

$$X_i = (X_{i1} + \dots + X_{ij} + \dots + X_{i,n}) + D_i \quad , \quad (4)$$

with

- $X_i$   $\hat{=}$  gross output of sector  $i$ ;
- $X_{ij}$   $\hat{=}$  deliveries from sector  $i$  to  $j$ ; and
- $D_i$   $\hat{=}$  deliveries from sector  $i$  to final demand.

This says that the gross output of a sector consists of the intermediate products sold to various production sectors and the final product  $D_i$  sold to the consumer. Or using the technical coefficients

$$a_{ij} = \frac{X_{ij}}{X_j} ,$$

$$X_i = \sum_{j=1}^n a_{ij} X_j + D_i , \quad (5)$$

in matrix form

$$\bar{X} = \bar{A} \bar{X} + \bar{D} , \quad (6)$$

with

$\bar{A}$   $\hat{=}$  matrix of the intersectorial technical coefficients  $a_{ij}$ .

Solving this equation, we find the gross output from each sector required to produce the final demand  $\bar{D}$  to be

$$\bar{X} = (\bar{E} - \bar{A})^{-1} \bar{D} , \quad (7)$$

with

$\bar{E}$   $\hat{=}$  the identity matrix.

Investment goods are part of the final demand good sector. Therefore, the additional gross output required to produce the extra investment  $I$  can be derived from

$$\bar{X}^I = [(\bar{E} - \bar{A})^{-1} D] + [(\bar{E} - \bar{A})^{-1} (\bar{D} + I)] ,$$

$$\bar{X}^I = (\bar{E} - \bar{A})^{-1} \bar{I} , \quad (8)$$

where  $\bar{X}^I$  describes the direct plus indirect output requirements of the sectors of the economy required for the construction of the energy facility.

Up to now we have evaluated the direct and indirect output requirements of the economy necessary for the investment I. However, we did not take into account the capital depreciation (consumption of capital) taking place by the production of the output  $\bar{X}^I$ . This capital consumed by the production process, of course, had been produced by the economy some time before, and, therefore, must be counted when calculating the overall output requirements of an investment I.

It is possible to include the portion of output consumed via the capital depreciation by adding the output requirements for capital consumption to equation (8). The overall output of sector i required for the investment I now can be written

$$X_i^I = \sum_{j=1}^n a_{ij} X_j^I + \sum_{i=1}^n C_{ij} + I_i \quad , \quad (9)$$

where  $C_{ij}$  is the amount of capital consumed in sector j to produce the gross output  $X_j$  which was delivered by sector i.

Introducing now the investment matrix  $\bar{B}$ , where  $b_{ij}$  is the fraction of investment (output) required from sector i per unit of investment in sector j, we get

$$X_i^I = \sum_{j=1}^n a_{ij} \cdot X_j^I + \sum_{j=1}^n b_{ij} C_j + I_i \quad , \quad (10)$$

with

$$b_{ij} = \frac{C_{ij}}{C_j} \quad \text{and} \quad \sum_{i=1}^n b_{ij} = 1 \quad .$$

Assuming direct proportionality between production and depreciation (capital consumption), the consumed capital in sector j is

$$C_j = r_j X_j \quad , \quad (11)$$

with

$r_j \hat{=}$  specific capital consumption of sector  $j$  per unit of output.

Introducing this relationship into the equation for  $X_i^I$ , we find

$$X_i^I = \sum_{j=1}^n a_{ij} X_j^I + \sum_{j=1}^n b_{ij} \cdot r_j \cdot X_j^I + I_i \quad ,$$

or

$$X_i^I = \sum_{j=1}^n (a_{ij} + b_{ij} \cdot r_j) X_j^I + I_i \quad , \quad (12)$$

$$i = 1, \dots, n \quad .$$

Written in matrix notation

$$\bar{X}^I = \bar{A}^* \bar{X}^I + \bar{I} \quad , \quad (13)$$

with

$$a_{ij}^* = a_{ij} + b_{ij} \cdot r_j \quad .$$

Assuming that the inverse matrix  $(\bar{E} - \bar{A}^*)^{-1}$  is found, the total overall output requirements to produce the investment  $I$  are

$$\bar{X}^I = (\bar{E} - \bar{A}^*)^{-1} \cdot I \quad . \quad (14)$$

This means that the total overall requirements of an energy investment could be found through combining the technical coefficient matrix of the intermediate production relations with an investment matrix and the specific capital consumption per unit of output of the sectors of the economy.

Equivalent results could be achieved by using an iterative procedure, starting from the capital consumption necessary to produce the direct and indirect output requirements for investment I, and then calculating the first round output requirements to produce the consumed capital  $\bar{C}$ . Starting then from the capital consumption for the production of  $\bar{C}$ , the next iteration step is made. The overall output requirements  $\bar{X}^I$  to produce the investment I are derived by summing up the output figures of the iterative steps.

### 1.2 Manpower and material requirements

The total manpower and material requirements for the construction of the energy facility can be calculated by multiplying the vector of the material respectively manpower requirements per unit of output of sector i with the output  $\bar{X}^I$ .

#### Manpower requirements

$$L = \bar{R}_L \cdot \bar{X}^I , \quad (15)$$

#### Material requirements

$$M = \bar{R}_M \cdot \bar{X}^I , \quad (16)$$

with

$\bar{R}_L \hat{=}$  vector of the direct manpower requirements per unit of output; and

$\bar{R}_M \hat{=}$  vector of the direct material requirements per unit of output.

### 1.3 Operational requirements

Different energy technologies require different combinations of sectorial input for their operation. Besides the investment requirements the operation requirements are the second important factor that influences the structure of the relationship between the energy sector and the rest of the economy.

Different input requirements of different energy technologies

or alternative energy supply systems are described--operating in terms of the Input-Output Matrix--by corresponding technical input coefficients of the energy sector in the intermediate product relations matrix.

Let us assume we have the matrix of the technical coefficients of an economy with only one energy sector, indicated by the index n

$$\bar{A} = \begin{pmatrix} a_{11} \cdots a_{1,n-1} & a_{1,n} \\ \vdots & \vdots \\ a_{n-1,1} \cdots a_{n-1,n-1} & \vdots \\ a_{n,1} \cdots \cdots \cdots a_{n,n} \end{pmatrix}$$

where  $a_{1,n}, \dots, a_{n-1,n}$  describe the direct input from the non-energy sectors required for the production of one unit of output of the energy sector.

The first step in the solution to calculate the total operational requirements of alternative supply systems now is to define the direct input coefficients  $a_{1,n}, \dots, a_{n,n}$  for the energy systems under consideration. These coefficients can be derived from a detailed analysis of the direct input requirements of the supply system.

The direct and indirect operational requirements of the alternative energy supply system can then be obtained from the inverse matrix

$$(\bar{E} - \bar{A}_K)^{-1}$$

where  $\bar{A}_K$  is the technical coefficients matrix of the economy with the energy system K.

The last column of the inverse matrix indicates the gross output from each sector required to produce one unit of final output of the energy sector. Multiplying with the final energy demand of the economy, we obtain the necessary production output

of the other sectors of the economy in order to provide this final energy demand.

Using this procedure we again have not taken into account the capital consumption (depreciation) necessary to produce the direct and indirect operational requirements of the energy sector.

To do that, we have to invest the extended technical coefficient matrix  $\bar{A}^*$  (with  $a_{ij}^* = a_{ij} + b_{ij} \cdot r_j$ , see equation (13)) for the alternative energy supply systems.

## 2. Dynamic Impact of Different Energy Strategies on the Economy

In the previous section a method was described to account for the overall output requirements needed by the economy to construct and to operate an energy facility or supply system. Thereby the time dependence of the required investments in the energy sector were neglected. Furthermore, the timing of the investments in the other sectors of the economy necessary to produce the required output for the energy sector were not taken into account.

However, it turns out that especially in the case of a rapid development of the energy system and in the case of fundamental changes in the energy supply structure, the dynamic aspects of the interactions between the energy system and the economy are of great importance.

Therefore, we will now extend the static approach described earlier to evaluate the time-phased overall output, manpower and material requirements of a candidate energy supply system.

### 2.1 Time-phased requirements of the investments of the energy sector

When a particular energy facility has to come on-line at a particular time, the construction of that facility must begin some years before. That means that the resource requirements of the facility are spread over the construction time of the plant. To take into account these time-phased investment requirements, the overall construction requirements must be allocated to the different years of construction.

Starting from the total number of each type of energy supply facility required to supply fuel mix in year  $t$ , the new capacities of energy supply facilities (taking into account the retirement of old facilities) of each type which must begin operation in year  $t$  are calculated.

The required new capacities in year  $t$  of energy technology  $K$  are given by

$$C_e^K(t) = \max[(K_e^K(t+1) - K_e^K(t)), 0] \quad . \quad (17)$$

The total investment requirement of supply technology  $K$  in year  $t$  can then be determined by the equation as given in [1]

$$I_e^K(t) = \sum_{\pi=t}^{t+1_K} S_e^K(\pi - t) k_e^K C_e^K(\pi) \quad , \quad (18)$$

with

$S_e^K(\pi - t) \hat{=}$  coefficients of investment distribution by the construction years of energy technology  $K$ ; and  
 $k_e^K \hat{=}$  capital investment per unit of capacity of energy technology  $K$ .

Multiplying  $I_e^K(t)$  with the vector  $\bar{F}_{e,i}^K$  of the sectorial expenditures per unit of investment in technology  $K$  and summing up over all technologies  $K$ , we obtain the sectorial investment requirements of the energy sector in year  $t$

$$\bar{I}_e(t) = \sum^K \bar{F}_{e,i}^K \cdot I_e^K(t) \quad . \quad (19)$$

To calculate the time-dependent direct and indirect output requirements for the investments into the energy sector, we can use equation (8) from the previous section

$$\bar{X}^I(t) = (\bar{E} - \bar{A})^{-1} \bar{I}_e(t) \quad . \quad (20)$$

Again we have not considered the investments of the other sectors

of the economy necessary to produce the investments of the energy sector.

To achieve this we can use the following procedure.

The time-dependent production capacity  $K_j(t)$  of sector  $j$  can be described as a function of the investment and depreciation rate

$$K_j(t + 1) = K_j(t) + C_j(t) - AK_j(t) \quad , \quad (21)$$

with

$K_j \hat{=}$  production capacity of sector  $j$ ;  
 $C_j(t) \hat{=}$  new capacity of sector  $j$  put into operation at year  $t$ ;  
and  
 $AK_j(t) \hat{=}$  retired capacity of sector  $j$ .

or

$$C_j(t) = K_j(t + 1) - K_j(t) + AK_j(t) \quad . \quad (22)$$

Assuming now that the maximum possible output  $X_j$  of sector  $j$  is proportional to the production capacity  $K_j(t)$

$$X_j(t) \leq \frac{1}{d_j} K_j(t) \quad ,$$

and that the depreciation of the production capacity is proportional to the production itself,

$$AK_j(t) = r_j X_j(t) \quad ,$$

we can write equation (22) as

$$C_j(t) = d_j X_j(t + 1) - d_j X_j(t) + r_j X_j(t) \quad . \quad (23)$$

For economical reasons  $C_j(t)$  normally could not become negative, and we get the time-dependent capacity expansion in the non-energy sectors of the economy by

$$C_j(t) = \max[C_j(t), 0] \quad . \quad (24)$$

The time-dependent investments for increasing the capacity in sector  $j$  can be described as

$$I_j(t) = \sum_{\pi=t}^{t+1} S_j(\pi - t) k_j C_j(t) \quad (25)$$

with

$S_j \triangleq$  coefficients of investment distribution by the construction years of sector  $j$ ; and

$k_j \triangleq$  capital investment per unit of capacity in sector  $j$ .

To solve this equation we need the time-dependent values of  $X_j(t)$ , the overall output of the non-economy sectors required to produce the investment  $\bar{I}_e(t)$  of the energy sector.

A simultaneous solution as described in the previous section for the static case is not possible. So we have to solve the equation by using an iterative procedure.

We start with the direct and indirect production levels for producing the energy investments received from equation (20), to calculate the required investment in the related sectors of the economy, following equations (23)-(25).

Introducing now the investment matrix  $\bar{B}$ , where  $b_{ij}$  is the fraction of investment (output) required from sector  $i$  per unit of investment in sector  $j$ , we receive the sectorial investment goods demand, necessary for the investment in the non-energy sectors

$$I_i(t) = \sum_{j=1}^n b_{ij} I_j(t) \quad , \quad (26)$$

or in matrix notation

$$\bar{I}(t) = \bar{B} \bar{I}(t) \quad .$$

The necessary output of the different sectors of the economy required for this induced investments can be obtained from

$$\bar{X}^1(t) = (\bar{E} - \bar{A})^{-1} \bar{I}(t) \quad , \quad (27)$$

where

1  $\hat{=}$  index for the first iterative step.

For the second step of the iteration we again have to start to calculate by applying equations (23)-(26) to the investment requirements in the non-energy sectors to produce the required output  $\bar{X}^1(t)$ .

Summing up the calculated output requirements of the different iterative steps, we receive the overall production of the different sectors of the economy necessary to produce the investment requirements  $\bar{I}_e(t)$  of the energy sector.

## 2.2 Time-phased operational requirements

The evaluation of the time-dependent operational requirements of a given energy policy starts with the calculation of the time-dependent input coefficients of the energy sector described in section 1.3. Assuming then that the input coefficients of the other sectors remain constant, we receive the time-dependent matrix  $\bar{A}(t)$  of the technical coefficients.

The direct and indirect yearly production of the non-energy sector required to operate the energy sector can then be obtained by solving the following equation

$$\bar{X}^0(t) = (\bar{E} - \bar{A}(t))^{-1} \cdot \bar{D}_e(t) \quad , \quad (28)$$

with

$\bar{X}^0(t) \hat{=}$  production of the non-energy sectors required for the operation of the energy sector; and  
 $\bar{D}_e(t) \hat{=}$  final demand for energy.

Now bringing the investment and operational requirements together,

we can calculate the overall requirements of a given energy policy.

Again we have to use an iterative procedure--the same as described in section 2.1--but now starting the iteration with the time-dependent investment requirements  $\bar{I}_e(t)$  of the energy strategy under consideration and the exogenous-given energy demand  $\bar{D}_e(t)$ , and using the dynamic technical coefficient matrix  $\bar{A}(t)$ .

In the first step of the iteration we solve the equation

$$\bar{X}^1(t) = (\bar{E} - \bar{A}(t))^{-1}(\bar{I}_e(t) + \bar{D}_e(t)) \quad , \quad (29)$$

for each time period under consideration. Thereafter we calculate the investment requirements of the non-energy sector of the economy  $I_j(t)$  by solving the equations (23)-(26). The received investment requirements  $\bar{I}(t)$  were used as input to equation (29) for the second iterative step

$$\bar{X}^2(t) = (\bar{E} - \bar{A}(t))^{-1}\bar{I}(t) \quad .$$

The overall output requirements of the non-energy sectors necessary for a given energy policy are received by summing up the production requirements of the different iterative steps.

$$\bar{X}(t) = \sum_{l=1}^L \bar{X}^l(t)$$

where

l = index of the iterative step; and

L = number of iterative steps.

The scheme of the calculation is illustrated in Figure 1.

### 3. The Assessment of Energy Imports

Alternative future energy policies differ not only, as outlined in the previous sections, referring to their output requirements

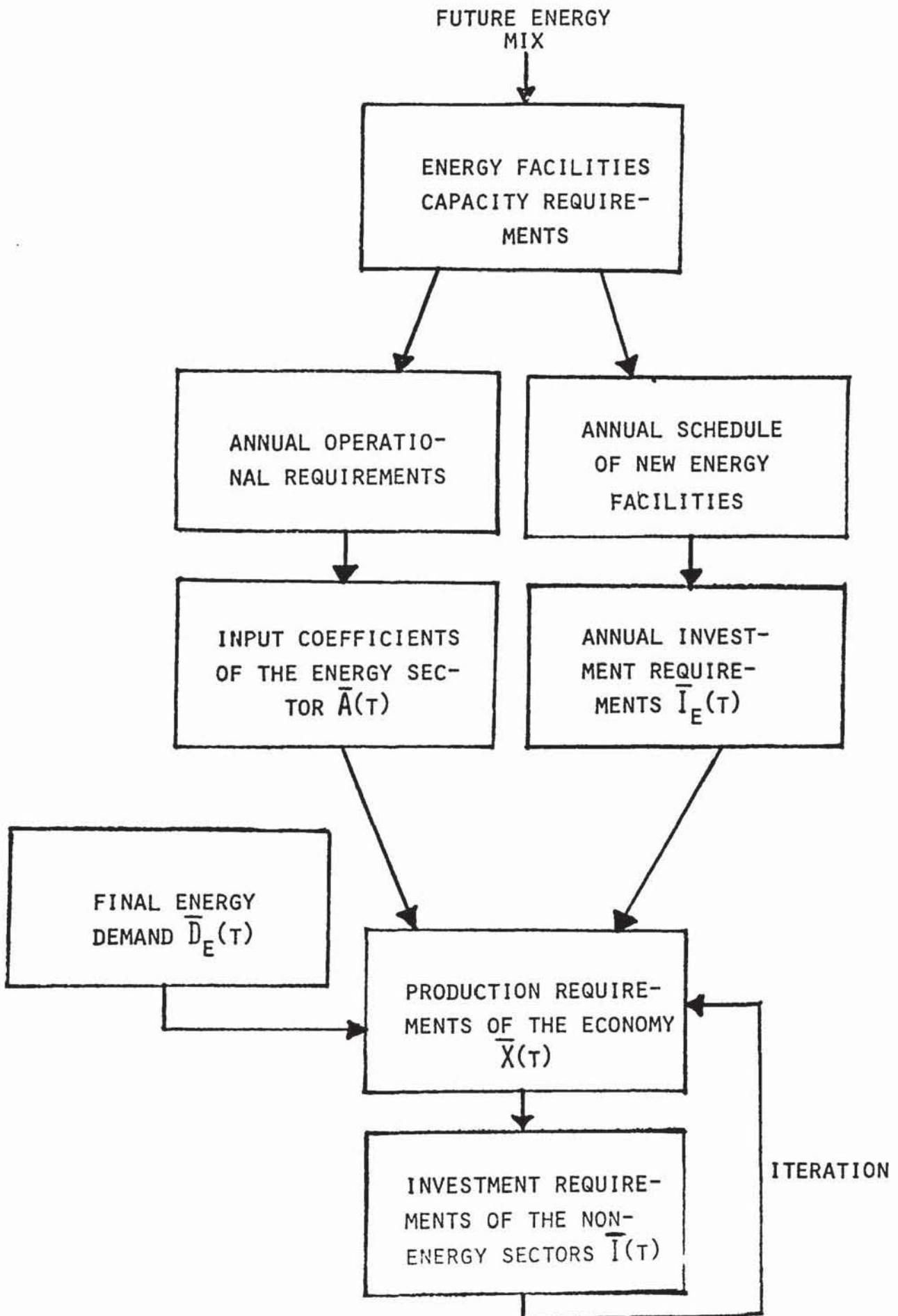


Figure 1: Scheme of calculation

of the different sectors of the economy; but also referring to the import requirements, for example, for non-native primary energy carriers.

In order to compare the production requirements of different economy sectors of alternative future energy policies, it is necessary to take into account their differences in using goods which have to be imported from other economies. There are several possibilities to account for the import requirements of an energy policy. One method applicable to the kind of import goods that are also produced by the economy, is to assess these imports with the output requirements of the economy sectors necessary to produce them by the economy.

Another possibility, which seems to make more sense when trying to find out the overall production requirements of an economy for different energy strategies, is based on the fact that the imports of the energy sector have to be paid by an equivalent value of export goods. Consequently, the imports of the energy sector are accounted for by the production necessary to produce these export goods. In practice we calculate the direct and indirect production output of the different sectors of the economy to produce one \$ worth of export goods. By multiplying the value of imports required for an energy strategy with this average production requirements per value of export, we obtain an assessment of the energy imports. This procedure allows for an consistent comparison of the overall production requirements of alternative energy policies.

#### References

- [1] "The Energy Supply Planning Model", Final Project Report, Bechtel Corporation, San Francisco, California, U.S.A., August 1975.
- [2] Kononov, Yu., "Modeling of the Influence of Energy Development on Different Branches of the National Economy", RR-76-11, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.