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DEVELOPMENT OF INTEGRATED MODELS FOR ENERGY-ECONOMY SYSTEMS ANALYSIS AT JAERI

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Development of Integrated Models for Energy-Economy Systems Analysis at JAERI

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This report, being a revision of the preprint for distribution to participants at IEA/ETSAP Workshop held, at JAERI, Tokyo, March 1984, describes the concept of the integrated models for energy-economy systems analysis now being carried out at JAERI.

In this model system, there contains four different categories of computer codes. The first one is a series of computer codes named as E^3-SD representatively, which are utilized to develop a dynamic scenario generation in a long-term energy economy evolution. The second one, of which the main constituents are the MARKAL, i.e. an optimal energy flow analizer, and the TRANS-I/O, i.e. a multi-sectoral economy analyzer, has been developed for the analysis of structural characteristics embodied in our energy-economy system. The third one is for a strategy analysis on nuclear power reactor installation and fuel cycle development, and its main constituent is the JALTES. The fourth one is for a cost-benefit-risk analysis including various kinds of data bases.

As the model system being still under development, but the idea of application of it to such a problem as "the role of the HTGR in the prospects of future energy supply" is also explained in the report.

Keywords: Energy, Economy, Interaction, Model, Reactor, Strategy,
Data Base, Systems Analysis, System Dynamics.

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* On leave from Maruzen Oil Co.

エネルギー経済システムズ解析の為の統合モデルの開発

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（1984年7月12日受理）

この報告書は，本年3月に日本原子力研究所東京本部において開催されたＩＥＡ／ＥＴＳＡＰ*ワークショップ（*国際エネルギー機関のエネルギー技術システムズ解析研究プロジェクト）で発表した論文に加筆したものであり，目下開発中のエネルギー経済システムズ解析の為の統合モデルの概念を説明している。

このモデルシステムには4カテゴリーに分けられる計算コードが含まれている。第1カテゴリーはE^3－ＳＤと名付けられ，一連の計算コードを含んでいるが，それらの計算コードは長期エネルギー経済活動の展開における動的シナリオの創出の為に使用される。第2カテゴリーにはエネルギーフロー最適化の為のＭＡＲＫＡＬコード及び多部門経済分析の為のＴＲＡＮＳ－Ｉ／Ｏを含むが，このカテゴリーのコードはエネルギー経済システムに内在する構造的な特性を解析する目的の為に開発された。第3カテゴリーのコードは動力炉の投入戦略及び核燃料サイクルの展開を分析する為のもので，主要コードはＪＡＬＴＥＳである。第4カテゴリーのものは費用，便益，リスク分析を行う。これには種々のデータベースをも含んでいる。

本モデルシステムはまだ開発中であるけれども，“将来のエネルギー供給においてＨＴＧＲが如何なる役割を果しうるか”といった問題分析への1応用についても述べられている。

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1. Introduction

Energy is one of the vital elements for living creatures. This energy itself is now gradually facing with some difficulties, that is, its utilization is going to be possible only after we can exploit high technology and enough capital. This is true especially for nuclear energy and renewable energy, even though these energy sources are abundant on the earth. For nuclear energy concerned, it has one more handicap, i.e. rather longer lead time to implement it in our energy system.

From these reasons, it can be claimed that the energy research and development should be conducted not only from technical point of view, but from economical and environmental considerations. Especially for such society which has entered already into the modest economic progress, further growth of economy will only be attained when economic resources are effectively allocated, and more or less our future world will be constrained by environmental issues resulting from anticipated increase in energy use. The conduct of energy research and development programme is also affected by these considerations.

Recognizing the importance of these consequences, the research works on energy systems analysis have been carried out at Japan Atomic Energy Research Institute since 1976. From these, we extract the activities of developing analytical models and show them schematically in Fig. 1.1.

The computer model contained in the first block can be utilized to intend to extract the vision of our energy-economy-social development, that is, to use it as scenario generator. On the other hand, the computer model in the second block is used for the analysis of structural characteristics of a given scenario. The third block provides an analytical tool which treats reactor strategy and fuel cycle analysis. To the fourth block, we are going to provide such tools as the one for cost-benefit-risk analysis and various data necessary for systems analysis. In the following, we will explain the concept of each model and present some results.

2. Model Descriptions

2.1 E^3 (Energy, Economics and Environment) System Dynamics Model Group.

(1) Needs

There are at present two basic approaches in the methodology of systems analysis[1]. The first is that favored by strategic analysts which emphasizes the prediction of future optimal patterns from the analysis of detailed data and static performances. The other is the system engineering approach which emphasizes the projection of future optimal paths from the generation of scenarios based on systems dynamic characteristics.

Energy strategy LP (Linear Programming) models, such as MARKAL[2], are very useful for strategic and structural analysis of total energy systems. However, these are mathematically static and have some difficulties to be adapted for energy projections or estimation problems. Basic scenarios descriptors, such as trends of socio-economic variables, supply/demand situation of energy, and cost estimations in future are kinds of input variables for these models. Thus, study opportunities and needs exist for system dynamics models group that could supply input data for these models.

While, a typical problem often cited in connection with energy-economic strategy analysis is the lack of appreciation of the results by end-users, policy makers and financial backers. Their questions are what happens in the system at disturbances like a sudden interruption of oil supply (oil embargo), how is the robustness of the optimal projection against economical impacts, when and how will the transition of technology occur, what is the effective policy for nuclear energy to obtain stable growth, and which policy is more effective in a particular time span, etc. To reply these questions and to render the results of system analysis more understandable and more useful to non-system specialists, more specific study needs exist to analyze dynamic characteristics of systems, such as policy impact analysis, disturbance analysis,robustness analysis, transition analysis and stable/unstable analysis of systems.

Corresponding to these necessities mentioned above, from 1980, we started to develop energy-economy system dynamics models. We have, at present, three models and one under developing; E^3 Macro MVAR (Multi Variables Auto Regressive) Models, Macro Energy SD (System Dynamics) Model, Macro Econometric Model, and Macro Energy-Economy SD Model. The subjects and time ranges covered by these models are shown in Figure 2.1.1.

(2) E^3 Macro MVAR Models

The constructing system of E^3 Macro MVAR Models consists of the computer data files which contain about 3500 items of energy-economy-environment time-series data, and of the computer program code which identifies multivariable auto-regressive models based on the results of analysis on causality of variables. The program code can immediately build up MVAR models within 500 variables and calculates dynamic characteristics of the system in the form of impulse response, step response, white noise response, and response to exogenous disturbances. The code can also calculate regulation type optimal solution with quadratic performance for the system obtained as the MVAR model$^{3)}$. The structure of this program code is shown in Figure 2.1.2, and the brief explanation of algorithms are in the following$^{4)}$.

k-dimensions stationary energy-economy-environment time-series data are described as

$$\{\mathbf{X}(s),\ s = 1,2,3,\ \ldots.,\ N\},$$
$$\mathbf{X}(s) = \{x_1(s),\ x_2(s),\ x_3(s)\ \ldots..,\ x_k(s)\}^T, \tag{2.1.1}$$

when $\mathbf{X}$ denotes observation value, and s sampling time. From these data within M time interval, we can obtain k dimension MVAR model,

$$\mathbf{X}(s) = \sum_{m=1}^{M} \mathbf{A}(m)\mathbf{X}(s-m) + \mathbf{U}(s), \tag{2.1.2}$$

where $\mathbf{A}(m)$ is a $k \times k$ martix and $\mathbf{U}(s)$ is a series of residuals obtained as the results of subtraction of past linear combinations. And, this description of stationary time-series model can be transformed to the equation,

$$\mathbf{Z}(s) = \Psi_o \mathbf{Z}(s-1) + \mathbf{V}_o(s), \tag{2.1.3}$$
$$\mathbf{X}(s) = \mathbf{H}_o \mathbf{Z}(s) \quad .$$

Here,

$$\mathbf{Z}(s) = \begin{bmatrix} \mathbf{X}(s) \\ \mathbf{X}(s-1) \\ \cdot \\ \cdot \\ \cdot \\ \mathbf{X}(s-M+1) \end{bmatrix}, \qquad \mathbf{V}_o(s) = \begin{bmatrix} \mathbf{U}(s) \\ \mathbf{0} \\ \cdot \\ \cdot \\ \cdot \\ \mathbf{0} \end{bmatrix},$$

$$\Psi_o = \begin{bmatrix} \mathbf{A}(1) & \mathbf{A}(2) & \mathbf{A}(3) & \cdots\cdots & \mathbf{A}(M-1) & \mathbf{A}(M) \\ \mathbf{I} & \mathbf{0} & \mathbf{0} & & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{I} & \mathbf{0} & & \mathbf{0} & \mathbf{0} \\ \vdots & \vdots & \vdots & & \vdots & \vdots \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & & \mathbf{I} & \mathbf{0} \end{bmatrix}$$

$$\mathbf{H}_o = [\,\mathbf{I}\,,\mathbf{0},\ \cdots\cdots,\mathbf{0},\mathbf{0},\ \cdots\cdots\mathbf{0}\,] \tag{2.1.4}$$

and $\mathbf{I}$ denotes an unit matrix and $\mathbf{0}$ a zero matrix. Again, we transform the equations (2.1.3) by the definition $\mathbf{Z}_o(s) = \mathbf{X}(s)$ and

$$\mathbf{Z}(s) = \begin{bmatrix} \mathbf{Z}_o(s) \\ \mathbf{Z}_1(s) \\ \vdots \\ \mathbf{Z}_{M-1}(s) \end{bmatrix} \quad , \tag{2.1.5}$$

then, equations (2.1.3) are replaced by following equations,

$$\begin{aligned} \mathbf{Z}(s) &= \Phi_0 \mathbf{Z}(s-1) + \mathbf{V}_0(s) \ , \\ \mathbf{X}(s) &= \mathbf{H}_0 \mathbf{Z}(s) \qquad\qquad , \end{aligned} \tag{2.1.6}$$

where

$$\Phi_0 = \begin{bmatrix} \mathbf{A}(1) & \mathbf{I} & \mathbf{0} \cdots & \mathbf{0} \\ \mathbf{A}(2) & \mathbf{0} & \mathbf{I} \cdots & \mathbf{0} \\ \vdots & \vdots & \vdots & \vdots \\ \mathbf{A}(M-1) & \mathbf{0} & \mathbf{0} \cdots & \mathbf{I} \\ \mathbf{A}(M) & \mathbf{0} & \mathbf{0} \cdots & \mathbf{0} \end{bmatrix} , \qquad \mathbf{V}_0(s) = \begin{bmatrix} \mathbf{U}(s) \\ \mathbf{0} \\ \vdots \\ \mathbf{0} \end{bmatrix},$$

$$\mathbf{H}_0 = [\,\mathbf{I} \quad \mathbf{0} \quad \mathbf{0} \cdots\cdots \quad \mathbf{0}\,] \ . \tag{2.1.7}$$

In this expression, state variables $\mathbf{X}(s)$ are composed of r endogenous variables $\mathbf{x}(s)$ and v exogenous variables $\mathbf{y}(s)$ and form a $(r+v)$ dimensions vertical vector. Therefore, if we pick up r variables and name them as $\mathbf{Z}$s, and if we define followings,

$$\mathbf{Z}_i(s) = \begin{array}{c} r \updownarrow \\ v \updownarrow \end{array}\begin{bmatrix} \mathbf{Z}_i{}^s \\ * \end{bmatrix} , \quad \mathbf{Z}_0(s) = \begin{array}{c} r \updownarrow \\ v \updownarrow \end{array}\begin{bmatrix} \mathbf{x}(s) \\ \mathbf{y}(s) \end{bmatrix} , \quad (i=0,1,2, \ldots\ldots, M-1) \tag{2.1.8}$$

$$\mathbf{Z}_s = \begin{array}{c} r\updownarrow \\ r\updownarrow \\ \\ \\ \\ r\updownarrow \end{array}\begin{bmatrix} \mathbf{Z}_0{}^s \\ \mathbf{Z}_1{}^s \\ \cdot \\ \cdot \\ \cdot \\ \mathbf{Z}_{M-1}{}^s \end{bmatrix} , \quad \mathbf{A}(m) = \begin{array}{cc} & \begin{array}{cc} \leftarrow r \rightarrow & \leftarrow v \rightarrow \end{array} \\ \begin{array}{c} r\updownarrow \\ \\ v\updownarrow \end{array} & \begin{bmatrix} \mathbf{a}_m & \mathbf{b}_m \\ & \\ * & * \end{bmatrix} \end{array} , \quad \mathbf{U}(s) = \begin{array}{c} r\updownarrow \\ \\ v\updownarrow \end{array}\begin{bmatrix} \mathbf{u}(s) \\ \\ * \end{bmatrix} , \tag{2.1.9}$$

then, we obtain following, so called discrete system state equations$^{4)}$.

$$\mathbf{Z}_s = \Phi \mathbf{Z}_{s-1} + \Gamma \mathbf{Y}_{s-1} + \mathbf{W}_s ,$$

$$\mathbf{X}(s) = \mathbf{H}\mathbf{Z}_s , \tag{2.1.10}$$

where

$$\Phi = \begin{bmatrix} \mathbf{a}_1 & \mathbf{I} & \mathbf{O} & \ldots\ldots & \mathbf{O} \\ \mathbf{a}_2 & \mathbf{O} & \mathbf{I} & \ldots\ldots & \mathbf{O} \\ \cdot & & & & \\ \cdot & & & & \\ \cdot & & & & \\ \mathbf{a}_{M-1} & \mathbf{O} & \mathbf{O} & \ldots\ldots & \mathbf{I} \\ \mathbf{a}_M & \mathbf{O} & \mathbf{O} & \ldots\ldots & \mathbf{O} \end{bmatrix} M\cdot r \times M\cdot r \text{ matrix} \qquad \Gamma = \begin{bmatrix} \mathbf{b}_1 \\ \mathbf{b}_2 \\ \cdot \\ \cdot \\ \cdot \\ \mathbf{b}_{M-1} \\ \mathbf{b}_M \end{bmatrix} M\cdot r, \qquad \mathbf{W}_s = \begin{bmatrix} \mathbf{u}(s) \\ \mathbf{O} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \mathbf{O} \end{bmatrix} M\cdot r,$$

$$\mathbf{H} = [\mathbf{I}, \mathbf{O}, \mathbf{O}, \ldots\ldots, \mathbf{O}, \mathbf{O}] ,$$

$$\mathbf{Y}_s = \mathbf{y}(s). \tag{2.1.11}$$

In these equations, Φ is called as transition matrix, Γ control matrix, and $\mathbf{H}$ output matrix. $\mathbf{Y}_{s-1}$ are control variables composed of v elements and determined as $\mathbf{Y}_{s-1} = \mathbf{K}\mathbf{Z}_s$ by the dynamic optimal control theory. It is commonly known from the theory of Maximum Principle or Dynamic Programming that optimal control law, $\mathbf{K}(\mathbf{K} = \lim_{i\to\infty} \mathbf{K}i)$, which minimizes the expectation of the quadratic performance index,

$$\mathbf{J}_I = E\{ \sum_{s=1}^{r} \mathbf{Z}_s{}^T \mathbf{Q}(s) \mathbf{Z}_s + \mathbf{Y}_{s-1}{}^T \mathbf{R}(s) \mathbf{Y}_{s-1} \} \tag{2.1.12}$$

subjected to the linear system equations (2.1.10 ∿ 2.1.11) for arbitrary initial condition is given by iterative calculations of the following equations[5]:

$$\mathbf{P}_0 = \mathbf{Q} \tag{2.1.13}$$

$$\mathbf{M}_i = \mathbf{P}_{i-1} - \mathbf{P}_{i-1}\Gamma(\mathbf{R}+\Gamma^T\mathbf{P}_{i-1}\Gamma)^{-1}\Gamma^T\mathbf{P}_{i-1} \tag{2.1.14}$$

$$\mathbf{P}_i = \Phi^T\mathbf{M}_i\Phi^T + \mathbf{Q} \tag{2.1.15}$$

$$\mathbf{K}_i = -(\mathbf{R}+\Gamma^T\mathbf{P}_{i-1}\Gamma)^{-1}\Gamma^T\mathbf{P}_{i-1}\Phi \tag{2.1.16}$$

$$\mathbf{Y}_{I-i} = \mathbf{K}_i\mathbf{Z}_{I-i} \tag{2.1.17}$$

where **Q** and **R** are weighting matrices.

While, once we obtain the system model in the form of (2.1.2) or (2.1.10), we can analyze dynamic characteristics of the system by calculating impulse response function $\{a_{ij}(m)\}$ in the algorithm[6]

$$a_{ij}(1) = A_{ij}(1)$$

$$a_{ij}(m) = A_{ij}(m) + \sum_{\ell=1}^{m-1} A_{ii}(\ell)a_{ij}(m-\ell), \quad (m=2,3,4,\ldots.), \tag{2.1.18}$$

and step response function $\{h_{ij}(m)\}$ in

$$h_{ij}(m) = \sum_{s=1}^{m} a_{ij}(s), \tag{2.1.19}$$

and other responses to exogenous disturbances similarly.

At present, as mentioned before, we have already furnished the computer code and data files and have some experiences on energy-economy systems analysis by this methods, especially in making small size macro models and in the causality study between energy, economy and environment variables. In the field of decision process or construction of large scale models, however, we faced some difficulties in selection of variables from the point of stationary process definition, therefore, we are now improving the program code by adding some filters and moving average functions in the data processing part.

(3) Macro Energy SD Model

Macro Energy SD Model is a kind of energy supply model and has been developed since 1982, referring to the Energy-Policy Model "FOSSIL-2" developed by DOE in the United States[7]. Using SD (System Dynamics) modeling technique[8], the model was designed as a simulation model composed of bi-linear differential equations describing the actual cause/effect relationships in energy systems of

Japan. The model is organized to represent adequately the relevant money and energy flows in the real-world system, and is divided into two parts, one determining the demand for various energy carriers and the other representing their supply structures. These two parts are adjusted by interactions on fuel demand, availability and price within constraints set by exogenous parameters. Demand adjustments occur in response to price and the shift of supply, while supply adjustments are achieved by changes in capacity utilization factors of production in short term and changes in production capacities through newly induced investment from profits in long term.

The model is composed of demand sector, demand/supply sector, financial sector, production sector, import and stock sector, and resource sector. These basic structures are shown in Figure 2.1.3. The demand sector specifies net energy demand as a function of GNP value, average energy price, and average energy availability. Then net energy demand is divided into fuel specific net demands. The GNP values are derived from the output of the macroeconometric equilibrium model described in section (4). The average energy price is weighted by relative fuel consumption and consumption/demand ratio. Each fuel price is modified by the amount of each fuel demand according to the share in total energy demand.

In the supply/demand balance sector, market price of each fuel is determined from the comparison of each fuels' demand with available production capacities. Increased demand increases utilization and price and, therefore, supply; reduced demand reduces utilization and price and, therefore, supply. Considering the profit margin and industry revenue, the market price is further modified to be the actual price.

In the financial sector, available funds for industry to invest new production capacities are calculated. The size of investment, production cost, scale of physical assets are taking into account. Once the amount of each investment needed for each industry is decided, available investments are allocated among the different technologies of energy production depending on a logistic allocation function.

The production sectors are divided into two types of production technologies; energy extraction technologies and energy conversion technologies. The former technologies are those which remove energy from the ground, e.g. coal mining, oil and natural gas production. The latter technologies include those which convert an energy into other useful forms of energy, e.g. electricity generation, coal liquefaction, coal gasification and synthetic natural gas production, etc.

In the production sector, the production capacity and the unit production cost of each energy technology are determined. The energy production in each energy production sub-sector is the function of demand/supply balances, and is adjusted by using capacity utilization factor in short range, and is adjusted by installing new capacities or retiring old capacities in long range. In the resource sector, such natural resources as oil, coal, and natural gas are constrained by the size of reserves, the limit to development in extraction technologies, the discovery rate of resources, and the exogenous political assumptions.

Since Japan imports a large amount of energy resources, energy import plays an important part in energy supply model. Moreover, it is very important subjects for us to estimate the amount of oil stock and the situation of import in such a case of energy crisis as oil embargo, therefore, the model should have another sector which treats import and stock of energy carriers. In the import and stock sector, the concept of suitable stock is introduced in parallel with the supply/demand balance, and the amount of spot import is determined after adjusting for the amounts of import, stock, and price. Additionaly, the amount of long term contract in energy import is also determined in similar functions.

This model has a full set of energy economic data from 1965 to 1982, and has been used for analysis of the energy supply situation of Japan. At present, we are brushing up the model not only from data base but also from partial improvements in model structure. Figure 2.1.4 is one of typical examples obtained from the simulation studies on the projection of final energy consumption in our country.

(4) Macro Econometric Model

Macro Econometric Model was organized from 1982 to estimate the economic situation of Japan in middle time range. The model is an equilibrium fixed-structural econometric model based on the assumption of neo-classical theorem9). Recently, in Japan, a lot of macro econometric models have been constructed10), however, most of them are based on the Keynesian theory and the decision theorem on effective demand. In the Keynesian-type model, the structure of supply is treated as an invariant scheme, therefore, it seems to have more certainties in short time range than in long time range. On the contrary, this model was designed to have some characteristics which put strength in supply side of economy; for example, labour force and financing variables are treated as constrained variables to demand side based on the modified Phillips curve and the assumption based on adaptive expectation theorem$^{11)}$.

In supply sector, we introduce R-T type macro production function$^{12)}$,

$$\log\left(\frac{V}{L}\right) = \alpha_0+\alpha_1 \log\frac{K}{L} + \alpha_2 \log\frac{P_E}{P} + \alpha_3 t, \tag{2.1.20}$$

where, V denotes gross national expenditure, L employment, K capital stocks, P_E energy price, P GNE deflator, t time trend, while $\alpha_0 \sim \alpha_3$ are parameters estimated from past statistic data. Because of the introduction of production function, price sector has a function composed of variables denoting the gap between demand and supply.

Moreover, it is said from the equation (2.1.20) that the increase in capital stock depending on the growth of the equipment investment increases supply abilities. From these dynamical characteristics of the model, we thought that the potential of economic-growth-ability could be considered in this model. The main purpose of the financial sector in conventional macro-econometric model is to analyze money supply accounts by demand function of money, and to set average rate of interest based on a bank rate and demand for investments funds.

However, in financial sector, crowdingout effect and the diversification of the capital investment are supposed to become specific trends in the economic situation of near future in Japan$^{13)}$. This model was designed to include the structure which can treat the impact on the interest rate by escalation in deficit financing caused by a large amount of national debt (so called crowdingout effect), and the impact on the financing structure by household behavior through the diversification in the method of individual accumulation in assets. The middle time range impact by structural change in labour supply could not be also ignored in this model because of the phenomena of distribution change in labour-age and increase of woman labour in recent situation of Japan$^{14)}$.

The basic structure of the model is shown in Figure 2.1.5 and the forms of the main functions in each sector are described in the followings. The function for a private consumption expenditure in final demand sector is

$$C = \alpha_4 + \alpha_5 \left(\frac{YD+AU}{PC}\right) + \alpha_6 \dot{PC}\left(\frac{YD+AU}{PC}\right) + \alpha_7 \left(\frac{T_{OP}}{P}\right)_{-1}, \tag{2.1.21}$$

where YD denotes property income, PC deflator of private final consumption expenditure, AU value of inventory valuation adjustment in private enterprise, T_{OP} private financial assets, P GNE deflator, while $\alpha_4 \sim \alpha_7$ are parameters estimated. The entrepreneurial income, Y_{cc}, in the distribution sector is obtained from the equation,

$$(Y_{cc}-A_c)/(Y+A) = \alpha_8 + \alpha_9(I_P-D_P)/Ve - \alpha_{10} i - \alpha_{11} W/P_w + \alpha_{12} P_w \, , \tag{2.1.22}$$

where A_c denotes the value of inventory valuation adjustment in private cooperative enterprise, W wage, Y national income, A total inventory valuation adjustment, I_P investment funds of private enterprise, D_P fixed capital comsumption by private enterprise, V_e gross domestic product, i contract interest rate of national bank, P_w wholesale price indexes, while $\alpha_8 \sim \alpha_{12}$ are parameters estimated. The wage function in wage-price sector is

$$W = \alpha_{13} - \alpha_{14} (U_0 + U_{-1}) + \alpha_{15} \dot{P}_c \, , \tag{2.1.23}$$

where U denotes unemployment rate, W wage, P_c private final consumption expenditure deflator, while $\alpha_{13} \sim \alpha_{15}$ are parameters estimated. The interest rate function of national bonds in the financial sector is

$$\begin{aligned} i_{gbx} = \alpha_{16} + \alpha_{17} (BGL_g - BG_g - BG_j) + \alpha_{18} i_N \\ + \alpha_{19} i_{eu} + \alpha_{20} (SD_a + SD_p) + \alpha_{21} R_{es}, \end{aligned} \tag{2.1.24}$$

where i_N denotes official bank rate, i_{eu} foreign interest rate, R_{es} foreign exchange rate, SD_a investment funds of corporation, SD_p investments funds of private enterprise, and BGL_g, BG_g, BG_j denotes the balance of various bounds respectively, while $\alpha_{16} \sim \alpha_{21}$ are parameters estimated from past statistic data.

The model are composed of almost 70 such macro functions as described and 40 definite equations in economics. Parameters informed in each function are estimated based on national statistic data base from 1965 till 1980, eg. Annual report on national account (EPA), Monthly labour statistics (EPA), Monthly economic statistics (JNB), Research report on labor (PMO), Wholesale price index (JNB), etc. Figure 2.1.6 shows one of examples of projections on main macroeconomy indices obtained from this model. The difference between case V_1 and V_2 are caused partially by the modification of wage function, and partially by the set of such exogenous variables as international trade. Dotted lines show the values which were used for Japanese calculation for phase 3-A of ETSAP. At present, the model is being modified in parameters from the point of time extention till 1983, and also is being improved in partial structure of functions.

(5) Macro Energy-Economy SD Model.

Macro E^2-SD Model is constructed by structural-invariant bi-linear dynamic equations and is able to be called as the system dynamics simulation model of national economy, however, it has both energy and economy variables homogeneously. The model is designed to provide scope of structural transition process of energy technology for longer term than the macro energy SD model, and to offer quantitative information on the political effects or impacts by large economic depression or inflation. Basic structure of this model can be shown in Fig. 2.1.7 and divided into financial, household, import and export, production, and government sector. The production sector simulates production activities by two-level CES function[15)] and consists of four sub-sectors; goods, capital, conventional and unconventional energy. The household sector treats the consumption of goods, supply of labour, saving and borrowing. The financial sector sets interest rate and simulates capital formation by the investment function. The import and export sector treats import of goods, capital, and energy. In the government sector the policies of wage, price, tax, social security, financing, and energy are determined. This model is now under developing and the data base is also under constructing.

(6) Others.

The models groups described in sections (2) ∿ (5) mainly deal with the problems of energy-economic interactions in Japan. We have not yet started to develop synthetic macro E^3 (energy, economy, environment) model by which we could estimate the environmental situation in future, because we have not yet succeeded to find out effective correlation between environmental indices and energy-economy variables from macroscopic and global point of view. As there are differences in amplitudes, time scale, and physical range between environmental variables and other variables, the existence of rational causality could not be detected in the analitical study by the macro MVAR model.

While, in recent years, a lot of SD type regional simulation models have been constructed for the purpose of making aids in siting decisions of energy facilities by forcasting the impact on regional socio-economic development[16). In Japan, the siting of nuclear power plant has become one of the large social problems under a promotion policy on nuclear energy, therefore, the needs of detailed analysis on regional E^3 effects caused by siting and operating of nuclear power plants become large.

At first, we had started to gather past statistic E^3 data of the special region where a large amount of energy facilities have been constructed. As the results of time-series analysis on these data, we could find the existence of some causalities within the small geographic range, and we decided to start to develop regional socio-economic, environmental model by using SD programming technique. Brief descriptions of the model are presented in section (3) of chapter 2.4 because of its large dependence on the data base and its characteristics included in cost/benefit/risk analysis of regional communities.

2.2 Multi-Sectoral Energy Economy Interaction Model E-I/O (Translog)

(1) Object

The main objective of developing the E-I/O (Translog) model is to provide an analytical tool which is capable of analyzing the impacts and effects being brought on economy progress through the introduction of various energy technologies.

To realize this, the model has to possess such capabilities as estimating energy demand which has to match with economic growth, as accounting the installed capacity of energy facilities and evaluating their availabilities which meet the demand. Also, the model can calculate the quantities of materials, capital, labor necessary for manufacturing, construction, and operation of energy facilities, and analyze the supply structure of those economic resources.

At the same time, the model has to be arranged to provide analytical capabilities for the analyses of the consequences introduced by new energy technology in national economy, for instance, impact to GDP growth, effect on private income, influences on market prices, balance of payments, etc.. The model should also be adaptable in the analysis of the back-pressure reactions which appear in the energy system from change of economy condition. From the consideration observed in the above, it can be said that our energy-economy interaction model should be constructed not only from mere conceptual interest but from wider applicability.

(2) Basic Assumptions

For constructing such an analytical tool, the frame and the structure of an energy-economy system should be defined precisely beforehand. To make this, we will first look at our social activities. Soon we can find that they are composed of various levels of activities which are ranging from consumption originated from each humanbeing survival to production being carried out as a group by use of technologies and natural resources. For accounting for the quantities of those activities properly, there arises first the necessity to extract the most fundamental constituents from the system.

The first thing we notice is how to modelize the sector classification in our economic transaction. In our present model, we introduce industry, household, government, and foreign sector as one of the most coarse classification. The second thing necessary for clarification is to question what kind of economic resources each sector will utilize to accomplish its desire.

For this prepossession, we must recognize to introduce the concept of primary economy resource element. Capital, labor, materials including energy, and technology are selected as those elements. The third thing to be considered is how to give a behavioral principle to each sector when it takes action in each system. Accordingly, we will introduce the following principles: in household sector, a principle of utility maximization is imposed on conduct of consumption deed; in industrial sector, a principle of minimizing production cost or maximizing output profit is applied when this sector executes production work. Role of government sector is aimed to keep the social unification in pursuits of social fairness and walfare with the utilization of such policy measures as taxes and subsidies which are exogenously given in our model system. In foreign sector, there may exist two major activities which relate to behavioral principle. One is the means how to keep trade balance and the other is the management of exchange rate to stabilize economic condition. We will treat these measures exogenously for the time being.

The fourth thing to be cleared is how to keep the balance between supply and demand imposed on various economic resources. In general, the price of goods and services may serve as auctional role. Beside these, however, we will install another measures, for instances, stock of goods and services, and availability of energy facilities. It is also very important for the model to keep an analytical capability, even if the system faces some intrinsic imbalances.

(3) System Constitution

The energy-economy interaction model described here is based on the combined methodologies of input-output, macro econometric, and energy flow analysis.

Sectoral classification of the input-output analysis is displayed in Fig. 2.2.1. The intermediate demand sector is first divided into two parts, i.e. non-energy industry sector and energy industry sector. The former is further divided into the following 23 sub-sectors, i.e. agriculture-forestry-fisheries, mining excluding coal and oil mining, ----, services on one hand. On the other hand, these 23 sub-sectors are aggregated into the following 4 coarse industrial sectors, i.e. an allied industries to produce commodities of life, an industry for producing primary materials, an industry for manufacturing, and an industry to supply miscellaneous services. The energy industry sector is further divided into the following 4 sub-sectors, i.e. coal mining and conversion of coal-related fuel, oil mining and conversion of oil-related fuel, gas mining and gas works, and electric utility and others.

Final demand sector is composed of consumption, capital formation, stock (denoted by J), export (FX), and import (M). For consumption concerned, its activity is accounted for by consumption outside households (CH), consumption of households (C), government consumption (GC). The capital formation is accounted for by private component and government component. The private component is furthermore subdivided into non-energy part and energy part. The latter is divided again into four parts according to the sectoral classification for energy subsectors.

Capital and labor are the primary factor inputs in industrial sector. When this sector conducts production work, it needs also intermediate goods and services of which some are imported. Capital and labor are appropriated at the sector of primary factor input, but the imported goods and services are treated in final demand sector. It is also necessary for industrial sector to include the role of production technology. However, except for energy technologies, we treat its effect as a technical factor.

Two options are provided for energy industry sector to allocate energy carrier. One is based on the MARKAL model 2) and the other is the built-in model which generates necessary information within its model framework. In either option, the behavior of this sector is analized from technological point of view, i.e. its constituents are not merely conceptual embodies but definite energy technologies.

One such technology configuration in the sector is exemplified in Fig. 2.2.2. The sector E_4, which is for electric and heat generation as well as for their transmission and distribution, contains miscellaneous power plants, for instance, fossil power plants, nuclear power plants, renewable power plants, heating plants, and the auxiliary energy facilities such as nuclear fuel cycle facilities. The sector E_3 includes such energy technologies as coal mining, coke production, coal liquefaction, coal gasification, etc..

(4) Behavior of Industrial Sector

Flow of goods and services in our model system is illustrated conceptually in Fig. 2.2.3. If we wish to argue about behavioral principle of industrial sector, it can be said that this sector will conduct its production work so as to minimize the input cost or to maximize the output profit. This behavioral principle can be formulated into an optimization problem that when sector j will produce its output X_j with the utilization of input production element X_{ij} $(i=1\sim I)$, the sector j will conduct its production work so as to minimize input cost or to maximize output profit under some technical constraints.

Let us introduce price P_j corresponding to output X_j and price P_{ij} to input production element X_{ij}, and denoteing the total cost and the profit by C_j and π_j respectively. By solving a cost minimization problem or a profit maximization problem under the constraint of $X_j = F_j(X_{1j}, X_{2j}, ---, X_{Ij})$, where F_j is a production function, we can obtain the following relations$^{17)}$:

$$\frac{\partial \ell n C_j}{\partial \ell n P_{ij}} = \frac{P_{ij}X_{ij}}{C_j}, \tag{2.2.1}$$

$$\frac{\partial \ell n P_j}{\partial \ell n P_{ij}} = \frac{P_{ij}X_{ij}}{P_j X_j}. \tag{2.2.2}$$

When the profit π_j is always kept to zero, $C_j = P_j X_j$ can be held. Then, the right-hand side of Eq. (2.2.1) is equal to that of Eq. (2.2.2). The right hand side has the meaning of cost share for input production element X_{ij}. We denote this as S_{ij}. The equations (2.2.1) and (2.2.2) tell us that the cost share S_{ij} for input production element X_{ij} can be derived from differentiation of the logarithmic cost function $\ell n C_j$ with respect to the logarithmic price $\ell n P_{ij}$ of input i paied by sector j or from differentiation of the logarithmic price $\ell n P_j$ of output received by sector j with respect to $\ell n P_{ij}$ (Shephard's lemma)^{18}.

By use of the cost share S_{ij}, we can calculate an input-output coefficient. Here, we will introduce the nominal input-output coefficient $a_{ij} (\equiv P_{ij}X_{ij}/C_j)$, i.e. the cost share of input i purchased by sector j, and the real coefficient a^*_{ij} $(\equiv X_{ij}/X_j)$, i.e. the quantity share of input i purchased by sector j. These coefficients are now calculated as follows:

$$a_{ij} = S_{ij}, \tag{2.2.3}$$

$$a^*_{ij} = a_{ij} \cdot (P_j/P_{ij}). \tag{2.2.4}$$

Since we now derived the general expression for calculating the input-output coefficient, we will proceed to the application of it. Let input production element X_{1j}, X_{2j}, ----, X_{23j} correspond to M_{1j}, M_{2j}, ----, M_{23j} which are goods and services produced in non-energy industry sector and purchased by sector j, X_{24j}, X_{25j}, ----, X_{27j} to E_{1j}, E_{2j}, ----, E_{4j} which are purchased by sector j from energy industry sector, X_{28j} to capital input K_j, X_{29j} to labor input L_j. Here, we introduce the expressions : $X_{M_ij} \Longleftrightarrow$

M_{ij}, $X_{E_{ij}} \Leftrightarrow E_{ij}$; where the symbolic notation "$\Leftrightarrow$" has the meaning of equivalency. Let M'_{1j}, M'_{2j}, ----, M'_{4j} be the aggregated input production elements which are purchased by sector j from coarse non-energy industrial sector 1∿4. Here again we introduce the expression: $X_{M'_{ij}} \Leftrightarrow M'_{ij}$.

Let the production function of sector j be chosen as $X_j = f_j(X_{1j}, X_{2j}$, ----, $X_{29j})$, and denote the cost function, which is dual to X_j, as $C_j = g_j(P_{1j}, P_{2j}$, ----, $P_{29j}, X_j)$. Suppose that the production function has the properties of linear homogeneity as well as of weak separability against $X_{M_{ij}}$ (i = 1∿23), $X_{M'_{ij}}$ (i = 1∿4), $X_{E_{ij}}$ (i = 1∿4), then the cost function C_j can be expressed with less variables:

$$C_j = g_j(P_{Mj}, P_{Ej}, P_{Kj}, P_{Lj}, X_j) , \tag{2.2.5}$$

$$P_{Mj} = P_{Mj}(P_{M'_1j}, P_{M'_2j}, ----, P_{M'_4j}) , \tag{2.2.6}$$

$$P_{M'_ij} = P_{M'_ij}(P_{M_1(i)j}, P_{M_2(i)j}, ----, P_{M_N(i)j}), \quad (i=1\sim 4), \tag{2.2.7}$$

$$P_{Ej} = P_{Ej}(P_{E_1j}, P_{E_2j}, ----, P_{E_4j}), \tag{2.2.8}$$

where $M_n(i)$ corresponds to the n th element of the sequence of M_{ij} which belongs to M'_{ij}.

It is an important problem to select a functional form of the production function. In our present model we utilize a translog function[19] for it. The translog function is said to have no such property as having a global concaveness, but a local concaveness can be assigned on it for any set of input production element. Further more, this function has a property of any substitutability among input elements so that it provides some flexibility in positive analysis.

In actual model simulation analysis, we don't use a production function f_j but a cost function C_j. For C_j, we employ a translog function. This supposes a Hicks' type[20] of technical progress. For P_{Mj}, $P_{M'_ij}$, P_{Ej}, we apply a homothetic translog function. These functions have the following functional forms:

$$\ell nA_j + \ell nC_j = \alpha_{0j} + \sum_i \alpha_{ij} \ell nP_{ij} + \frac{1}{2} \sum_i \sum_k \beta_{ikj} (\ell nP_{ij})(\ell nP_{kj}), \tag{2.2.9}$$

$$\ell nP_{\lambda j} = \alpha^{\lambda}_{0j} + \sum_i \alpha^{\lambda}_{ij} \ell nP_{ij} + \frac{1}{2} \sum_i \sum_k \beta^{\lambda}_{ikj} (\ell nP_{ij})(\ell nP_{kj}), \tag{2.2.10}$$

where subscripts i, k in Eq. (2.2.9) represent K, L, E, M respectively, and A_j is a factor for technical progress in sector j. In Eq. (2.2.10), subscripts i,k cover M'_1, M'_2, ----, M'_4 when $\lambda = M$, and $M_1(i)$, $M_2(i)$, ----, $M_N(i)$ when $\lambda = M'_i$, and E_1, E_2, ----, E_4 when $\lambda = E$. Now, the cost share S^{ν}_{ij} can be derived by use of the Shephard's lemma:

$$S^{\nu}_{ij} = \alpha^{\nu}_{ij} + \sum_k \beta^{\nu}_{ikj} \ln P_{kj} , \qquad (2.2.11)$$

where the quantities substituting $\nu = 0$ cover K, L, E, M cost share, $\nu = M$ for M'_1, M'_2, ----, M'_4 cost share, and $\nu = E$ for E_1, E_2, ----, E_4 cost share. For $\nu = M'_i (i=1 \sim 4)$, they cover $M_1(i)$, $M_2(i)$, ----, $M_N(i)$ cost share.

Using the above cost share, we can generate nominal input-output coefficients (which are not yet corrected for indirect taxes) in the following way:

$$a'_{ij} = \begin{cases} S_{ij} & i \in (K,L) \\ S_{Mj} \cdot S^{M}_{M'_k j} \cdot S^{M'_k}_{M_i(k)j} & i \in (M_1, M_2, \text{----}, M_{23}) \\ S_{Ej} \cdot S^{E}_{E_i j} & i \in (E_1, E_2, \text{----}, E_4) , \end{cases} \qquad (2.2.12)$$

where subscript j cover M_1, M_2, ----, M_{23}. The input-output coefficients between energy industry sectors and those from non-energy industrial sector to energy industry sector are determined at the block of energy flow analysis.

When applying tax correction t_j to a'_{ij}, we obtain $a_{ij} = a'_{ij}/(1+t_j)$. The real input-output coefficients a^{*}_{ij} can now be drived from Eq. (2.2.4). On that occation, we need P_j. But this P_j can be derived from Eq. (2.2.9), if we generate the cost function C_j with the condition of X_j being normalized to 1.0.

Let us proceed to the explanation of input-output coefficient for energy industry sector. For each energy technology g, the following quantities are obtained from the block of energy flow analysis: newly installed capacity A(g), capacity stock S(g), working activity W(g), quantity EI(g,f) of input energy carrier f, and EO(g,f) for output energy carrier. In addition, input fraction $e_{E_i j}(f)$ of energy carrier f to sector j from sector E_i, $e_{E_i E_j}(f)$ to sector E_j from sector E_i, and $e_{E_i F}(f)$ to final demand sector F from sector E_i are also obtained. These fractions are all in the nature of intermediate information, so that they are adjusted at every time when the interaction calculation between energy flow analysis and input-output analysis is executed.

Denoting the total output from sector E_i and the input to sector E_j from sector E_i as X_{E_i} and $X_{E_iE_j}$ respectively, we have the following equations:

$$X_{E_j} = \sum_f \sum_{g\epsilon E_j} EO(g,f) , \qquad (2.2.13)$$

$$X_{E_iE_j} = \sum_f \{e_{E_iE_j}(f) \sum_{g\epsilon E_i} EO(g,f)\} . \qquad (2.2.14)$$

The real input-output coefficients $a^*_{E_iE_j}$ can now be derived from $a^*_{E_iE_j} = X_{E_iE_j}/X_{E_j}$.

The energy input X_{E_ij} to sector j from energy sector E_i can be calculated as $a^*_{E_ij}X_j$ by utilizing $a^*_{E_ij}$ which is obtained from Eq. (2.2.12). On the other hand, the quantity X_{E_ij} must fulfill the balance condition from supply side:

$$X_{E_ij} = a^*_{E_ij} X_j = \sum_f \{e_{E_ij}(f) \sum_{g\epsilon E_j} EO(g,f)\} , \qquad (2.2.15)$$

where the left-hand side is determined from the input-output analysis, while the right-hand side from the energy flow analysis. In energy flow analysis, an optimization calculation is made to search an optimal allocation of energy carrier f in sector j under the constraint of keeping total energy demand in the level $a^*_{E_ij} X_j$. If the balance between supply and demand can not be held, some adjustments will be made at economy block through the reevaluations of $a^*_{E_ij}$ and X_j. These adjustments will continue till the balance could be attained.

The energy input X_{E_iF} to final demand sector F from sector E_i is calculated in the following way by use of each economic activity FD_k (k = CH, C, CG, J, EX) and input coefficient $e_k(f)$:

$$X_{E_iF} = \sum_f \sum_k e_k(f)FD_k = \sum_f \{e_{E_iF}(f) \sum_{g\epsilon E_i} EO(g,f)\} , \qquad (2.2.16)$$

where the coefficients $e_k(f)$, $e_{E_iF}(f)$ come from energy flow analysis, and these are of course reevaluated at every iteration calculation executed between energy flow analysis and input-output analysis.

Input production element to the energy sector E_j is composed of the elements X_{iE_j}, $X_{E_iE_j}$, X_{KE_j}, X_{LE_j}, and X_{ME_j}. The element $X_{E_iE_j}$ is already defined by Eq. (2.2.14). The element X_{ME_j}, i.e. the imported goods and services to sector j from foreign sector, is treated at the final demand sector. For calculating X_{iE_j}, X_{KE_j}, X_{LE_j}, the unit cost $C(\mu,g)$ (where μ

represents capital investment cost when μ = INV, operation and maintenance cost when μ = FIX or VAR, and fuel related cost when μ = FUL) of energy technology g which is installed in sector E_j, should be broken down beforehand into the input elements which are purchased from sector j. In our model, this breakdown is made in the following way.

Let the quantity of goods and services purchased from sector j at time period t be $q_j(t)$, and let $P_j(t)$ be its purchasing price, then the cost C(t) can be expressed by such a quantity as the summation of $P_j(t)q_j(t)$ for all possible j. Suppose the constituent ratio $\theta_j(q)$ of $q_j(t)$ to q(t) varies with the level of q(t), the cost C(t) can then be expressed as the quantity of q(t) multiplied with average price P(t) which is constructed from $P_j(t)$ using $\theta_j(q)$ as weighting factors. Appling this expression to $C(\mu,g)$, we can obtain the following cost partition:

$$C(\mu,g) = C^* (\mu,g) \sum_j \theta_j(C^*,\mu,g)\ P_{ig}\ , \qquad (2.2.17)$$

where $C^*(\mu,g)$ is total quantity for cost item μ, and P_{jg} is the purchasing price of goods and services from sector j for energy technology g.

Nominal input-output coefficients a_{iE_j} from sector i to sector E_j is defined by such a quantity as the ratio of the operation and maintenance cost plus the fuel related cost of technology g, which belongs to sector E_j, to the total output value of sector E_j:

$$\begin{aligned} a_{iE_j} &\equiv (P_{iE_j} X_{iE_j})/(P_{E_j} X_{E_j}) \\ &= \Big\{ \sum_{g \epsilon E_j} [C^*(\mathrm{FIX},g)\ \theta_i\ (C^*,\mathrm{FIX},g)\ S\ (g) + \\ &\qquad C^*(\mathrm{VAR},g)\ \theta_i\ (C^*,\mathrm{VAR},g)\ W\ (g) + \\ &\qquad C^*(\mathrm{FUL},g)\ \theta_i\ (C^*,\mathrm{FUL},g) EI(g)] \\ &\qquad P_{ig} \Big\} / (P_{E_j} X_{E_j})\ , \end{aligned} \qquad (2.2.18)$$

where EI(g) is total energy carrier input to technology g, and is obtained as the summation of EI(g,f) with respect to f belonging to sector E_j. Here, we will make one remark that from the partitioning cost components of fixed operation and maintenance cost we should exclude the personnel cost because this cost component is treated at the primary factor input sector. The real input-output coefficient $a^*_{iE_j}$ is calculated again from Eq. (2.2.4).

Nominal input capital coefficient a_{KE_j} of sector E_j can be defined by use of capital stock KE_{E_j} of sector j in the following way:

$$a_{KE_j} = KE_{E_j}/(P_{E_j}X_{E_j}) \ . \qquad (2.2.19)$$

The capital stock KE_{E_j} can now be estimated from the following information: newly installed capacity A(g) of technology g; partitioning data of C*(INV,g), $\theta_i(C^*,\mathrm{INV},g)$ for unit capital cost C(INV,g); purchasing price P_{ig}. We have now the following relations:

$$KE_{E_j} = \sum_{g\epsilon E_i} \sum_i KE_i(g) \ , \qquad (2.2.20)$$

$$KE_i(g) = KE_{i-1}(g) - DE_i(g) + IE_i(g), \qquad (2.2.21)$$

$$DE_i(g) = \left\{ \sum_{u=-n(g)}^{-1} IE_{iu}(g) \right\} / n(g), \qquad (2.2.22)$$

$$IE_i(g) = C^*(\mathrm{INV},g)\ \theta_i\ (C^*,\mathrm{INV},g)A(g)\ P_{ig} \ , \qquad (2.2.23)$$

where n(g) is the lifetime of energy technology g. $IE_i(g)$ is the capital cost disaggregated into sector j, which is necessary for installation of capacity A(g). $DE_i(g)$ is the depreciation of capital, which is also disaggregated into sector j. $KE_i(g)$ is the capital stock at present time period and $KE_{i-1}(g)$ for preceding time period. When we know capital purchasing price P_{KE_j}, the real coefficient $a^*_{KE_j}$ can be calculated from Eq. (2.2.4).

Nominal input labor coefficient a_{LE_j} of sector E_j can be defined as $a_{LE_j} = P_{LE_j}X_{LE_j}/(P_{E_j}X_{E_j})$. Here $P_{LE_j}X_{LE_j}$ is the input value of labor to sector E_j, and the input labor to sector E_j, X_{LE_j}, is then obtained from the summation of input labor L(g) for energy technology g with respect to such g belonging to sector E_j. The real coefficient $a^*_{LE_j}$ can also be derived from Eq. (2.2.4).

To treat the production price $P_i(i\epsilon\{E_i\})$ and the purchasing price $P_{ij}(i\epsilon\{M_i,E_i\},\ j\epsilon\{M_j,E_j\})$ endogenously, we will introduce the following relations:

$$P_{ij} = \overline{AP}_{ij}\cdot(1+t_i)\cdot P_i \ , \qquad (2.2.24)$$

$$P_{E_i} = \sum_{g,f\epsilon E_i} P(f)EO(g,f) / \sum_{g,f\epsilon E_i} EO(g,f) \ , \qquad (2.2.25)$$

where $\overline{AP}_{ij}$ are mark-up factors, representing price difference among sectors. P(f) is the price of energy carrier f. The price P_i, P_{ij} can now be determined in the following way: by use of $\{P_{Kj}\}$, $\{P_{Lj}\}$ determined at the block of primary input factor market and of $\{P_{Mj}\}$, $\{P_{Ej}\}$, the output price P_j can be calculated from Eq. (2.2.9); the prices $\{P_{Mj}\}$, $\{P_{Ej}\}$ are determined from Eq.

(2.210) by use of $\{P_{M'_i j}\}$, $\{P_{E_i E_j}\}$; $\{PM'_{ij}\}$ is now determined from Eq. (2.2.10) by use of $\{P_{M_n(i)j}\}$; here $\{P_{E_i E_j}\}$ and $\{P_{M_n(i)j}\}$ are the element member of $\{P_{ij}\}$.

Output X_j of sector j can now be calculated by use of such quantities, i.e. real input-output coefficient a^*_{ij}, indigenous final demand FD_j, export of goods and services EX_j, import of goods and services M_j:

$$\begin{pmatrix} \mathbf{X}_C \\ \mathbf{X}_E \end{pmatrix} = \begin{bmatrix} \mathbf{I}_{CC} - (\mathbf{I}_{CC} - \mathbf{M}^*_{CC})\mathbf{A}^*_{CC}, & -(\mathbf{I}_{EC} - \mathbf{M}^*_{EC})\mathbf{A}^*_{CE} \\ -\mathbf{A}^*_{EC} & ; \quad \mathbf{I}_{EE} - \mathbf{A}^*_{EE} \end{bmatrix}^{-1} \left\{ \begin{bmatrix} \mathbf{I}_{CC} - \mathbf{M}^*_{CC}, & \mathbf{O}_{CE} \\ \mathbf{O}_{EC} & , \mathbf{I}_{EE} \end{bmatrix} \times \right.$$

$$\left. \begin{pmatrix} \mathbf{FD}_C \\ \mathbf{FD}_E \end{pmatrix} + \begin{pmatrix} \mathbf{EX}_C \\ \mathbf{EX}_E \end{pmatrix} - \begin{bmatrix} \mathbf{O}_{CC} & \mathbf{O}_{CE} \\ \mathbf{O}_{EC} & \mathbf{P}_{EE} \end{bmatrix} \begin{pmatrix} \mathbf{O}_C \\ \mathbf{M}_E \end{pmatrix} \right\}, \qquad (2.2.26)$$

where $\mathbf{X}_C$ is a vector of which elements are output X_j of non-energy sector, while $\mathbf{X}_E$ for energy sector. Vector $\mathbf{FD}_C$ and $\mathbf{FD}_E$ are the corresponding indigenous final demand vectors, and both $\mathbf{EX}_C$ and $\mathbf{EX}_E$ for export of goods and services. Imported goods except energy carrier are all treated as competitive goods against domestically available goods. The matrix elements of $\mathbf{A}^*_{CC}$, $\mathbf{A}^*_{CE}$, $\mathbf{A}^*_{EC}$, $\mathbf{A}^*_{EE}$ are (a^*_{ij}), $(a^*_{iE_j})$, $(a^*_{E_i j})$, $(a^*_{E_i E_j})$, respectively. $\mathbf{M}_{CC}$ is a diagonal matrix of which element m_i is a ratio of imported goods and services to the sum of total intermediate input and indigenous final demand. $\mathbf{I}_{CC}$, $\mathbf{I}_{EE}$ are unit matrices, $\mathbf{O}_{CC}$, $\mathbf{O}_{CE}$, $\mathbf{O}_{EC}$ are zero matrices. $\mathbf{P}_{EE}$ is a diagonal matrix of which the element is PM_{E_i}/P_{E_i}, where PM_{E_i} is the average price of imported fuel carrier.

(5) Behavior of Final Demand Sector

To make our energy-economy interaction model complete as a closed form, we must treat final demands endogeneously. This is equivalent to introduce an accounting model for each component of final demand, i.e. consumption, capital formation, stock, export, and import. In our present model, the accounting methods employed are generally based on macro-econometric model, that is, by providing such accounting block as financial accounts, government and foreign accounts, ------ We build each behaivoral model.

The most important role of the household block is to generate the information of total private consumption expenditure and labor supply. Of course, price deflator of consumption goods and services as well as converter of these goods and services to intermediate supply are also determined in this block.

Total private consumption expenditure C/PC in real is calculated by the following equation:

$$\ell n(C/PC) = F[\ell n(YD/PC),\ \ell n(W_{-1}/PC),\ \ell nC_{-1},\ (\Delta PC/PC)\ell n(YD/PC),\ \ell n(YR/YP),\ \ell n(YT/YCT),\ GINI,\ VA]\ , \qquad (2.2.27)$$

where YD/PC is real disposable income. The roles of each variable and each parameter in the above function are the followings: W_{-1}/PC represents the effect of financial assets; C_{-1} measures the impact of consumption level experienced in preceding time period; $(\Delta PC/PC)\ell n(YD/PC)$ represents the impact of consumer price variation; YR/YP is introduced to measure the impact of property income; YT/YCT is for measuring the impact of transitory income; GINI represents the effect of income stratum; VA is for inclusion of the impact of the ratio of effective labor demand to effective supply.

Supply of labor LS is estimated by the following equations:

$$LS = \overline{LH} - LJ, \qquad (2.2.28)$$

$$LJ = L(W_{-1},\ YD,\ \Delta PC/PC,\ VA \text{ or } U), \qquad (2.2.29)$$

where $\overline{LH}$ is total hour available for household sector, determined from demographic consideration. LJ is leisure demand, and U is unemployment rate.

Consumption goods and services C_j purchased from sector j can be derived from total private consumption expenditure C and share function AVC_j. AVC_j can be derived from an indirect utility function V after application of the Shephard's lemma. In our model analysis, we utilize again the following translog function:

$$\ell nV = \sum_i \alpha_i^C\ \ell nPC_i + \frac{1}{2} \sum_i \sum_j \beta_{ij}^C (\ell nPC_i)(\ell nPC_j)\ , \qquad (2.2.30)$$

$$AVC_i = \frac{\partial \ell nV}{\partial \ell nPC_i} = \alpha_i^C + \sum_j \beta_{ij}^C\ \ell nPC_j\ , \qquad (2.2.31)$$

where subscript i covers M_1, M_2, ----, M_{23}. It holds $V = PC \cdot C$. In actual analysis, the function V is estimated with the constraint $C = 1.0$. Using AVC_i, we obtain the final expressions for Ci and PC:

$$Ci = AVC_i \cdot C\ , \qquad (2.2.32)$$

$$\ell n(PC/PC_{-1}) = \sum_i AVC_i \cdot \ell n(PC_i/PC_{i-1}) \ . \qquad (2.2.33)$$

Here, it is noticed that Eq. (2.2.33) is equivalent to Eq. (2.2.30), because it can be derived from time differentiation of Eq. (2.2.30). Moreover, we introduce the following relation:

$$PC_i = \overline{APC}_i \cdot (1+T_i) \cdot P_i \quad , \qquad (2.2.33)$$

where PC_i is the price corresponding to C_j, and $\overline{APC_i}$ is a mark-up factor. We now found the way to determine all of PC_i, AVC_i, C_i, PC, C, endogenously.

The fund available for private investment comprises the earning from labor saling and the earning from capital service. From the route of labor saling, wage earning YL → gross private income YP → private disposable income YD → private savings S and value of private wealth W are determined at financial accounts block according to the direction of the arrow symbol. From the route of capital service, the earning from capital service YK → corporate retained earnings SU → corporate savings SC are determined in the same way. With the corrections of government deficity DG, net claims on rest of world DR, provisions for fixed capital consumption DP, etc., net fund FUND can be determined from S and SC.

Investment demand is accounted for by non-energy part IP and energy part IE. Between them, the relation FUND = IP + IE should be held. The quantity of IE is accounted for at energy industry block. Investment share functions as well as investment price deflators, disaggregated into sector j, are also determined here, and capital stocks of nonenergy sector are accounted for also.

In government and foreign block, the following quantities are accounted for: tax revenues; government consumption expenditure; government deficity; government savings; import and export of goods and services; tansfers of incomes; deficity in rest of world, etc..

In the block for primary factor inputs, both supply and demand of labor service as well as for capital service are accounted for, and through balance checking for them the realizing prices of both labor service and capital service are determined in it.

Balance between supply and demand is in general attained by adjusting various price variables. However, it is also true that all of economic resource variables do not always fill equilibrium condition between supply and demand. Under certain circumstances, we need to know the degree of imbalance itself. From this reason, we install some checking measures in our model system in addition to stock variable J_i and availability factor $\zeta(g)$.

(6) Input Data Base

When we work this model, we need a lot of input data. The most fundamentals of these are the followings: (i) various coefficients for cost functions; (ii) various coefficients for indirect utility function; (iii) various coefficients contained in such functions representing private consumption expenditure, leisure demand; (iv) various coefficients determining investment shares, and converters from sector j to capital formation; (v) technical data of energy technology, for instance, fuel utilization efficiency, technical lifetime, maximum available capacity factor, etc.; (vi) cost partitioning data for energy technology. It needs a lot of works and a lot of considerations to generate these information, however we do not mention about this furtheremore in this report.

(7) Interporation Test

We will make one remark here that this model is still under development. However, most of the input data have been prepared, and the interporation tests of various functions have already been finished. From the works of interpolation tests, we have gotten a good feeling for usability of this model. In Table 2.2.1 we show the comparative results for cost share of input production elements citing electric machinery and appliances sector as an example. In Fig. 2.2.4, we present one example of regression analysis for private consumption expenditure and leisure function. In Table 2.2.2, a few example of cost partitioning for energy technologies are shown.

2.3 Long-Term Reactor Strategy Model JALTES

(1) Background

Development and utilization of nuclear energy are and will remain the major subjects in the energy policy of Japan, which has very poor domestic energy resources in comparison with its demand for energy. Substantial contribution of nuclear energy can be expected, however, only at the expense of other resources such as a huge amount of capital, high-level technologies, sufficient time for R&D and for installation of commercial plants. Therefore it is quite essential to build the rational and scrupulous RD & D program based on the enough prospect toward far future.

The objective of developing the JALTES model is primarily to contribute on planning the future RD & D of nuclear energy by providing the information about optimum strategy for reactor development, future demands on nuclear fuels and fuel cycle services, the cost of the system, and the possible impacts to the environment.

In JAERI the study on long-term strategy for nuclear energy development was initiated in 1969, and the computer models such as FUEL-DEMAND21),22), its revised versions23), STRATEGY-LP24) were developed and utilized in the study of the various fuel cycle systems25),26),27),28). The first version of the JALTES model was completed in 1976 based on the models mentioned above. The model was then modified to focus on the nuclear power generating system and to simulate the fuel and fuel material flows more accurately. The revised version, JALTES-II, has been used to investigate the possible role of the advanced thermal reactor (ATR)29), to examine the strategies to make effective use of plutonium30), and for other studies. The brief description on JALTES-II and an example of analysis are presented in the following.

(2) General Description

The outline of JALTES-II reactor strategy analysis is illustrated in Fig. 2.3.1. The model covers all types of nuclear power plants and the related fuel cycles. The capacity of each reactor type in the system is determined by the linear programming technique. The objective function for the optimization problem can be taken as a cumulative consumption of natural uranium with or without uranium recycle, or a total system cost, or others. Constraints can be given on an annual electricity generation, installed capacity of each reactor type or total installed capacity, stocks of fissile plutonium, reprocessing activities, an annual system cost, and others.

Inputs to set up an optimization problem are : A. scenario assumptions such as a time horizon, system configuration, an objective function and constraints, B. reactor characteristics such as a lifetime, fuel burnup, contents of fuel materials (U, Th, Pu, U-233) in each mode of fuel, investment and O&M costs, and C. fuel cycle characteristics such as lead and lag in the timing of uranium enrichment, fuel fabrication, spent fuel reprocessing, and so on, loss of material in each of these processes.

Outputs from the model are information on : A. reactors such as installed capacity and electricity generation by reactor types, B. materials and fuel cycle services such as consumptions of nuclear energy resources, supply and demand balances of each fuel material, demands for the service of enrichment, fuel fabrication, spent fuel reprocessing, and C. annual system cost by reactor types.

JALTES-II can be also used, as a simulation type model, to calculate the output quantities based on the nuclear energy program given exogeneously.

(3) Fuel Cycle Model

In JALTES-II unit time period corresponds to one year, and the planning horizon can be set with the time length up to 99 years starting from an arbitrary calendar year. Additions to the capacity in years prior to the start year can be given exogeneously to take account of their contribution on the capacity stocks, requirements on fuels and fuel cycle services within a planning horizon. The example of fuel charge and discharge schedule for a single reactor is shown in Fig. 2.3.2, while the illustration of the nuclear fuel cycle system modeled in JALTES-II is given in Fig. 2.3.3.

In the reactor fueling/refueling model, as indicated in Fig. 2.3.2, distinction is made for the fresh fuels between charged to the initial core and charged to the equilibrium core, and also for the spent fuels between discharged from the initial core, discharged from the equilibrium core, and discharged from the final core. Discharge of the initial core starts with a specified lag time after initial loading. Spent fuels discharged annually from the initial core are assumed same to each other in both quality and quantity. Fuels charged annually to the equilibrium core are normally discharged after a certain dwelling time, while those charged at the last several time periods in the reactor lifetime form the final core and discharged at the same time. Discharge of the final core is carried out immediately after the permanent shut-down of the reactor. Specifications and performances of fuels utilized in each reactor type can vary over time period, so that it is possible to change the fuel type of a particular reactor at a certain time period such as changing the fuel type of the ATR at the year 2010 from the MOX fuel to the enriched uranium fuel. However it is noted that the change of fuel type does not take place as a result of optimization. It is one of the assumptions to set up an optimization problem.

The major processes in the nuclear fuel cycle are included in the model as shown in Fig. 2.3.3. Differences in operation timings of processes and loss of material in each process are considered. In the front-end procurement of resources, conversion to UF_6, uranium enrichment, conversion to oxides, and fuel fabrication are carried out at different time stages and corresponding to the demand for fabricated fuels. In the back-end all spent fuels are resprocessed with a specified lag time after discharge from the reactor. Fuel materials recovered through reprocessing are reconverted and recycled, but those recovered more than the requirements are stored and utilized when necessary. Demand and supply balances of fuel materials are taken at the inlet of enrichment process for enrichment feed materials (natural uranium to be enriched and recovered uranium with a higher percentage of U-235 than natural uranium), and at the inlet of fabrication process for other materials. As indicated here, recovered uranium with a higher U-235 percentage than natural uranium is fed to enrichment process, while that with a lower U-235 percentage is treated in the same category as enrichment tails. This basic rule stands with the only exception that recovered uranium from a particular reactor type can be, through special instruction, used in another particular reactor type regardless to its U-235 content. In this case recovered uranium is fed directly to fabrication process even if it has a higher U-235 percentage than natural uranium. JALTES-II has another notable option in its fuel cycle model such that all or a part of spent fuels from all or specified reactor types can be stored without reprocessed. In this case fuel materials are not recovered at all or are recovered only from a part of spent fuels which are reprocessed.

(4) Equations

The variable in the optimization problem is the annual addition to capacity of each reactor type X(i,t). Here X(i,t) is expressed in terms of thermal output, and i and t denote reactor type and time period, respectively. The objective function and all constraints are structured as the linear combination of X(i,t). Among many equations incorporated in JALTES-II, the most fundamental ones are presented below.

Installed capacity of reactor type i at time period t is defined as

$$P(i,t) = \sum_{s=t-\ell(i)+1}^{t} e(i)\cdot X(i,s) \quad , \qquad (2.3.1)$$

where e(i) and ℓ(i) are thermal efficiency in generating electricity and reactor lifetime, respectively. Electricity generated by reactor type i at time period t is then derived from

$$Q(i,t) = h\cdot g(i,t)\cdot P(i,t) \ , \qquad (2.3.2)$$

where g(i,t) is load factor and h is number of hours in a year.

In JALTES-II reactor fuel is accounted for in terms of fuel materials such as uranium, plutonium, thorium, U-233. Amounts of fuel material j charged to the initial core (IC) and the equilibrium core (EC) of reactor type i at time period t are expressed as

$$K1(j,i,t) = k1(j,i,t)\cdot \frac{1}{W(i,t)} \cdot X(i,t) \quad , \qquad (2.3.3)$$

$$K2(j,i,t) = k2(j,i,t)\cdot \frac{d\cdot g(i,t)}{B(i,t)} \cdot \sum_{s=t-\ell(i)+1}^{t-r(i)} X(i,s) \quad , \qquad (2.3.4)$$

respectively. Here k1(j,i,t) is the weight ratio of fuel material j charged to the IC over total heavy metals charged to the IC, and k2(j,i,t) is the weight ratio of fuel material j charged to the EC over total heavy metals charged to the EC. W(i,t) is specific power, while B(i,t) is average burnup of fuels in the EC. r(i) represents time difference between initial loading and the first discharge from the IC. d is number of days in a year.

Amounts of fuel material j discharged from the IC, the EC, and the final core (FC) are derived from equations

$$KR1(j,i,t) = \sum_{s=t-r(i)-d(i)+1}^{t-r(i)} kr1(j,i,s)\cdot \frac{1}{W(i,s)} \cdot X(i,s) \ , \qquad (2.3.5)$$

$$KR2(j,i,t) = kr2(j,i,t-d(i))\cdot \frac{d\cdot g(i,t-d(i))}{B(i,t-d(i))} \cdot \sum_{s=t-\ell(i)+1}^{t-r(i)-d(i)} X(i,s) \quad , \qquad (2.3.6)$$

$$KR3(j,i,t) = kr3(j,i,t)\cdot \frac{1}{W(i,t)} \cdot X(i,t-\ell(i)) \quad , \qquad (2.3.7)$$

respectively. Here kr1(j,i,t) is the weight ratio of fuel material j discharged annually from the IC over total heavy metals charged to the IC, kr2(j,i,t) is the weight ratio of fuel material j discharged from the EC over total heavy metals charged to the EC, and kr3(j,i,t) is the weight ratio of fuel material j discharged from the FC over total heavy metals charged to the IC. d(i) denotes dwelling time of fuel in the equilibrium core.

(6) Example of analysis

The example of strategy analysis conducted with JALTES-II is now presented. The utilization of plutonium in thermal reactors was surveyed in this example with the time horizon 1970-2050. The capacity schedule of each reactor type was determined by minimizing cumulative consumption of natural uranium under the constraint that total capacity in each year meets the demand for capacity specified exogeneously. The constraint was also given on the plutonium stock so that import of plutonium be not allowed. Reactor types included were the light water reactor with enriched uranium fuel (LWR), the light water reactor with MOX fuel (LWR(Pu)), the advanced thermal reactor with MOX fuel (ATR), and the fast breeder reactor (FBR). No constraint was given to the capacity of the LWR, while the date and rate of introduction of the LWR(Pu) and the ATR were restricted. The rate of introducing the FBR was also restricted during the 20 years after commercialization.

Among the outputs for this problem, the annual additions to capacity and the installed capacity of each reactor type are given in Fig. 2.3.4, while the net and gross cumulative consumption of natural uranium and the stock of fissile plutonium are given in Fig. 2.3.5. Here net and gross in natural uranium consumption refer to whether recycle of uranium is taken into account or not. According to the results, the LWR was installed in this example up to the year 2029, and only the FBR was installed thereafter. The LWR(Pu) and the ATR were introduced almost to their upper limits given exogeneously. The stock of fissile plutonium remained less than 80 ton until around the year 2040 and then increased rapidly as a result of self-sustaining of the FBR. The results in this simple case provides some insights on the potential of the LWR(Pu) and the ATR in reducing natural uranium consumption through the effective use of plutonium and also on the conditions affecting this potential. The quantitative evaluation on the effectiveness of plutonium utilization in thermal reactors will possibly be made by studying such comparagive cases as without thermal reactors using plutonium or with the different constraints on the capacity schedule of the FBR.

(7) Future Improvements

Fuel cycle system can be simulated in JALTES-II in sufficient degree of detail for the purpose of analyzing the long-term reactor strategy. However each process in the system is described only in terms of services and the concept of capacity is not adopted. Another shortcoming is that a single reactor type cannot use more than one fuel type at the same time. In the case of the FBR, for example, the current approach is to introduce a hypothetical fuel which has specifications averaged for core and blanket. Accordingly, the major items for future improvements are to model an individual process in the fuel cycle as a technology, to allow the storage of reactor fuels in relation to the above improvement, and to modify reactor fueling model to accept more than one fuel type at the same time. The works on improvement including these items have been already initiated.

2.4 Cost, Benefit, Risk Analysis Approach and Data Base

(1) Structure of Energy Consumption

The structure of energy consumption in our country has changed significantly since the first oil crisis, that is, a large oil price hike has given great influences not only upon economic growth but also upon oil consumption increasing year by year before that time. Especially for industry sectors, where a large amount of oil was consumed as feedstock or heat sources, the situation was very serious. As the result, each of industry sectors was forced to promote rational use of energy under the slogans "promotion of energy saving" and "break away from oil to alternative energy sources".

Under those social and economic situations, we had a necessity to investigate the actual circumstances of energy consumption in all industry sectors and to make a consideration for stabilizing supplies of energy sources, which would be relied on new energy technologies in future. In this context, we had the survey studies twice. The first study was mainly directed to energy intensive industries such as iron and steel, chemicals, ceramics and stone, pulp and paper, etc., in order to analyze a tendency for energy consumption immediately after the first oil crisis.31) The second study was for less energy intensive industries such as machinery, textile, agriculture and forestry, food industry, etc.,.32) Through these studies, the transition in the characteristics of energy consumption in each industry were identified and the structure of the energy use, especially the use of process heat, was investigated in detail.

The information obtained here is quite useful for various subjects such as studying the long-term strategy on the direct use of nuclear process heat or structuring the industrial process model as an essential component of the useful energy demand model to be developed. Among the outcomes of the above studies, one notable example is illustrated in Fig. 2.4.1. This figure shows the amount of final energy consumed in the form of heat at each range of process temperature. The heat here includes low temperature heat and thermal energy of steam for private electric power generation. However, it does not include thermal energy of steam for electric power generation by public utilities. As indicated in the figure, major part of energy at the temperature below 300°C is consumed in the residential and commercial sector and less energy intensive industries. While most process heat consumed in chemicals, paper and pulp, oil refining is in the temperature range 300°C ∿ 800°C. The process heat at the temperature above 800°C is consumed almost exclusively by iron and steel and ceramics.

Besides the above task, the detailed study on the energy consumption in the petrochemical industry was carried out.[33)] In this study, the average specific energy consumption was estimated for each of the major 17 petrochemical products or semi-products involved in ethylene-group, propylene-group, butane-butylene-group, and decomposing oil group. Here the specific energy consumption represented as energy consumed to produce one unit of the product through the individual production process. According to the study, the specific energy consumption estimated was high in producing ethylene, BTX, stylene-monomer, and polyethylene with the low and middle pressure processes in this order.

(2) Technology Data Base

Efforts have been also made in developing the data base on characteristics of energy technologies as a component of the comprehensive data base for the energy and economy models described above. Followings are brief description on the current status of this task.

a) Nuclear Technologies

As the fundamental data base for nuclear technologies, reactor characteristics (overall performances and fueling characteristics) have been compiled for various reactor types at a commercial scale. The data items cover the inputs to the JALTES-II model. The reactor types involved are the LWR (BWR and PWR), the ATR, the CANDU, the FBR, and the VHTR. Several fuel types are considered for each of these reactor types. For the electric power plants or heating plants employing the above reactor types, the cost data are collected generally with a higher degree of detail than the inputs to MARKAL. Both technical data and cost data have been investigated in detail for the application technologies of the VHTR process heat such as the coal to SNG or coal to methanol processes. Detailed technical and cost data have been also investigated extensively for the nuclear fuel cycle technologies. Here emphasis is naturally placed on the LWR fuel cycle, and the reference plant is assumed to characterize each technology.

b) Non-nuclear Technologies

The data base for non-nuclear technologies comprises the technical data and cost data generally corresponding to the inputs to MARKAL. For conventional electricity generation technologies, however, comparatively affluent background information is stored.

Among new technologies in this category, characteristics of coal liquefaction and gasification technologies under development have been surveyed[34]. Despite of difficulties in getting the latest and reliable sources under the recent circumstances, the information on the estimated costs and technical performances has been obtained for the various processes including SRC-I, SRC-II, H-Coal, Sasol, Mobil-MTG, Lurgi, H-gas, and BI-gas.

(c) Capital Coefficients of Energy Technologies

As an essential part of the data base for energy-economy interaction analysis, disaggregated investment costs to derive capital coefficients have been estimated for the major energy technologies including the nuclear fuel cycle technologies[35],[36]. The basic procedure for estimation is: a. classify the cost items into more than 20 industry sectors, b. estimate the total investment cost for unit production capacity of the reference plant, c. estimate the disaggregated investment cost and their fractions in the total cost according to the above industrial classification. The capital coefficient can be derived through the equation (2.2.19). The technologies involved here are the LWR power plant and the associated fuel cycle facilities (conversion to UF_6, uranium enrichment, UO_2 & MOX fuel fabrications, reprocessing, waste storage and disposal), the commercial VHTR plant and the heat application systems (coal to SNG and coal to methanol), the conventional coal-fired power plant, the LNG-fired power plant, the coal liquefaction plant (Synthoil process), and the gasification plant (BI gas process).

(3) Regional Socio-Economic, Environment Data Base and SD Model.

The siting of nuclear power plants and fossil power plants have been considered to have large socio-economic-environmental impacts on a regional community. The purpose of this study, at first, is to investigate and assess social and economic impacts upon people and their communities resulting from the construction and operation of nuclear power plants, and to generate hypotheses about such impacts for future testing. A more ambitious purpose is the extension or broadening of environmental impact assessment to include not only the social environment but also biophysical environment.

The pre-analytical study on collected data concludes that the primary impact of the nuclear power plant in communities was the massive increase in property tax payments paid to the local communities by the utilities. Second order consequences of the direct, first-order economic impact were increase in industrial production and private income of residents in the region.

Consequently, reflecting the results of the analysis mentioned above, we started to develop the regional socio-economic-environment SD model which has in basic structure 14 sectors as shown in Figure 2.4.2, namely, population, labour, dwelling, land use, transportation, primary industry, secondary industry, tertiary industry, public facilities, energy, income, financial, water resources, and environment.

Special features of this model compared with other conventional models in Japan are to put force in water and energy sector, and to treat detail in the scheme of public financial sector. Environmental sector has air pollution, water pollution, and waste subsectors and can take into account the indirect impact on environment through the increase of activity in industries caused by siting energy facilities. The present theme in the development of this model is to extend the structure of the model and broadening socio-economic environmental impact assessment to include biophysical environment. Conceptual design at present is shown in Figure 2.4.3; the classification of the damage is shown in (a), and the calculation flow of effects of damage is shown in (b).

The first problem is that the pollutant loading should be transformed into pollutant distribution by use of the diffusion model, however, the conventional diffusion models have too detailed algorithm to connect with the macro environmental model. We should study on simplify the diffusion model to an acceptable size. The second problem is that the eco-system affected by pollution has space distribution and the values in three dimension should be projected into the values in one dimension.

The third problem is that the degrees of ecological damage by harmful materials should be estimated in qualitatively. In general, damage may be counted by the damage function that defines the damage by expouse and concentration depending on time, however, examples of these functions and data in epidemiology have not yet been obtained for us.

3. Conclusion

The research and development on systems analysis have in general no final goal, because analytical methods, system models and data bases should by nature be improved through experiences of application. Receiving the critisism on output results, reflecting social needs for the subject of analysis, and exploiting more useful information and advanced analytical methods, we should always make such efforts as revising models, renewing data bases, and expanding applicabilities, etc. From these points of view, we have the following problems necessary for improvement furthermore.

In the first block in Figure 1.1, we should promote the application of such theories as the identification and estimation, the stability analysis, and the multi objective optimization. In the second block, the Multi-Sectoral E-I/O Model should include an option for normative analysis rather than the present descriptive one, and should also be added a sub-model which estimates the useful energy demand. In the third block, in addition to the model improvements described before we are now developing a new programming language to generate the matrix of standard format for the MPS/X software. The new language, the problem description (PD) language, will enable modelers to make matrix and report generators using ordinary mathematical expressions.

In the forth block, we should study on the applications of the theory of social welfare function and the theory of teams as effective and coordinative accounting methods, and also study on the applications of the theory of decision making under risk or under uncertainties as the useful method of decision algorithm.

Considering the aspect of the application of these methodologies mentioned in this paper, the models as a whole organize a system to deal with comprehensive subjects of systems analysis. At present we have one such subject, that is, analysis on "the role of the HTGR in the prospects of future energy supply." as shown in Figure 3.1.1.

The subject contains many tasks; eg. VHTR strategy in advanced reactor types, long term demand projection in supply/demand of high temperature nuclear heat, estimation of competitivity of the nuclear heat technology in total energy system, impact analysis of nuclear heat on national economy and environment by cost/benefit analysis approach, and identifying the path of R&D in the field of nuclear heat technology. Corresponding to these many tasks, each model and data base organize a methodological system as described in Figure 3.1.1.

Acknowledgement

We are indebted to many people in the development of these models mentioned in this paper. We wishes to express our thanks to Shoji Yoshikoshi of CRC (*1) for the work in energy-economy SD model, Shigeki Yamazaki of CRC for the work of econometric model, Toshiro Fujiwara of JEJ (*2) for the work of data base of MVAR codes, Toshihiko Akita and Takashi Oshika of MRI(*3) for the work of multi-sectoral energy-economy interaction model, Akihiro Ishibashi of CRC for the work of JALTES model, Itsuo Murano and Akibumi Sugawara of MRI for regional macro environment model, Hiroshi Okazoe and Ken Sogabe of MRI for the work of energy consumption data base, Shinjiro Sakamoto and Shozo Nakaguchi of JANP research consortium (*4) for the work of data base on VHTR and utilization system of nuclear heat.

(*1) CRC - Century Research Center Co.

(*2) JEJ - Japan Economic Journal.

(*3) MRI - Mitsubishi Research Institute.

(*4) JANP - Research consortium; Japan Association for Nuclear Process-Heat.

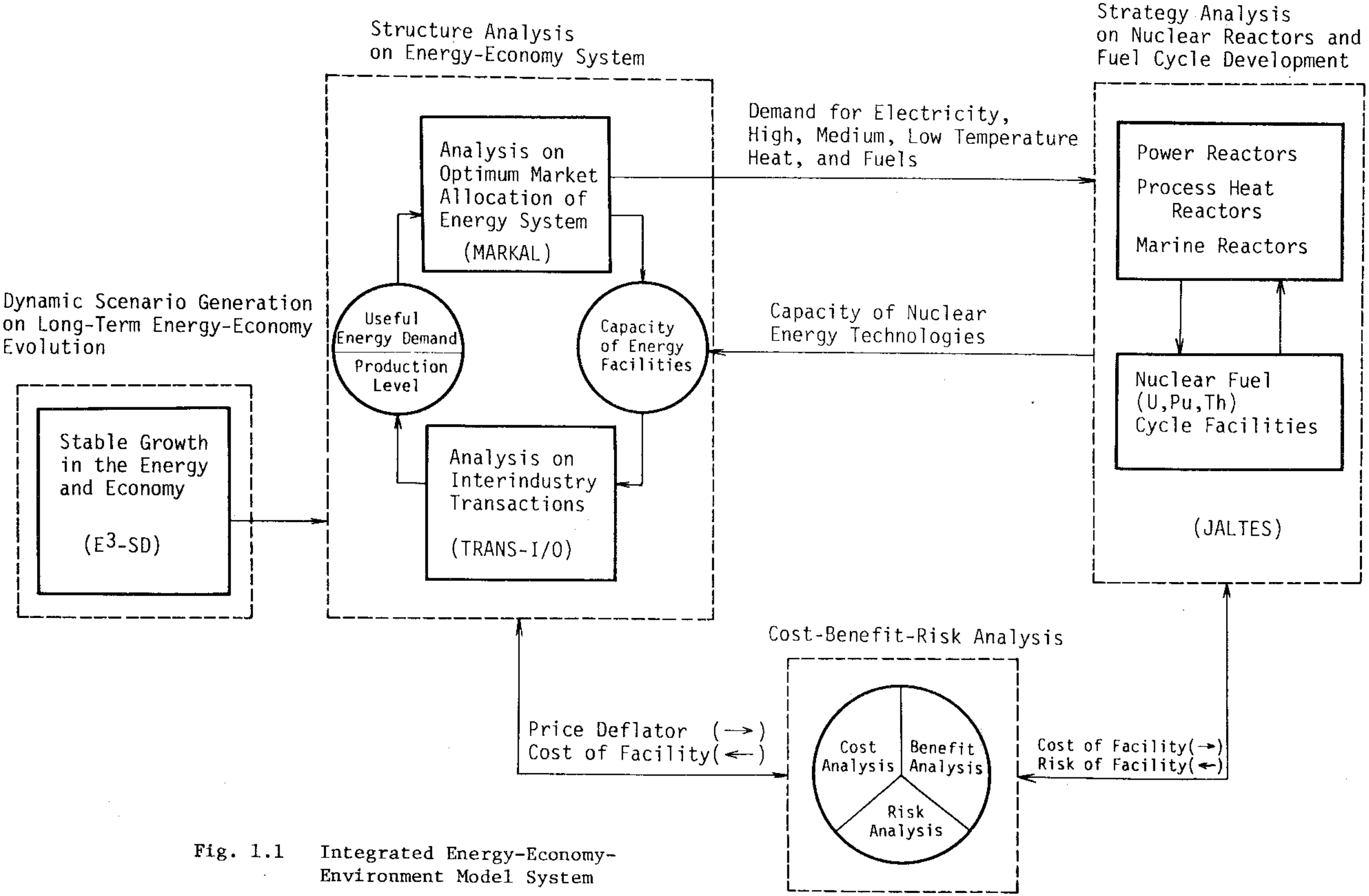


Fig. 1.1 Integrated Energy-Economy-Environment Model System

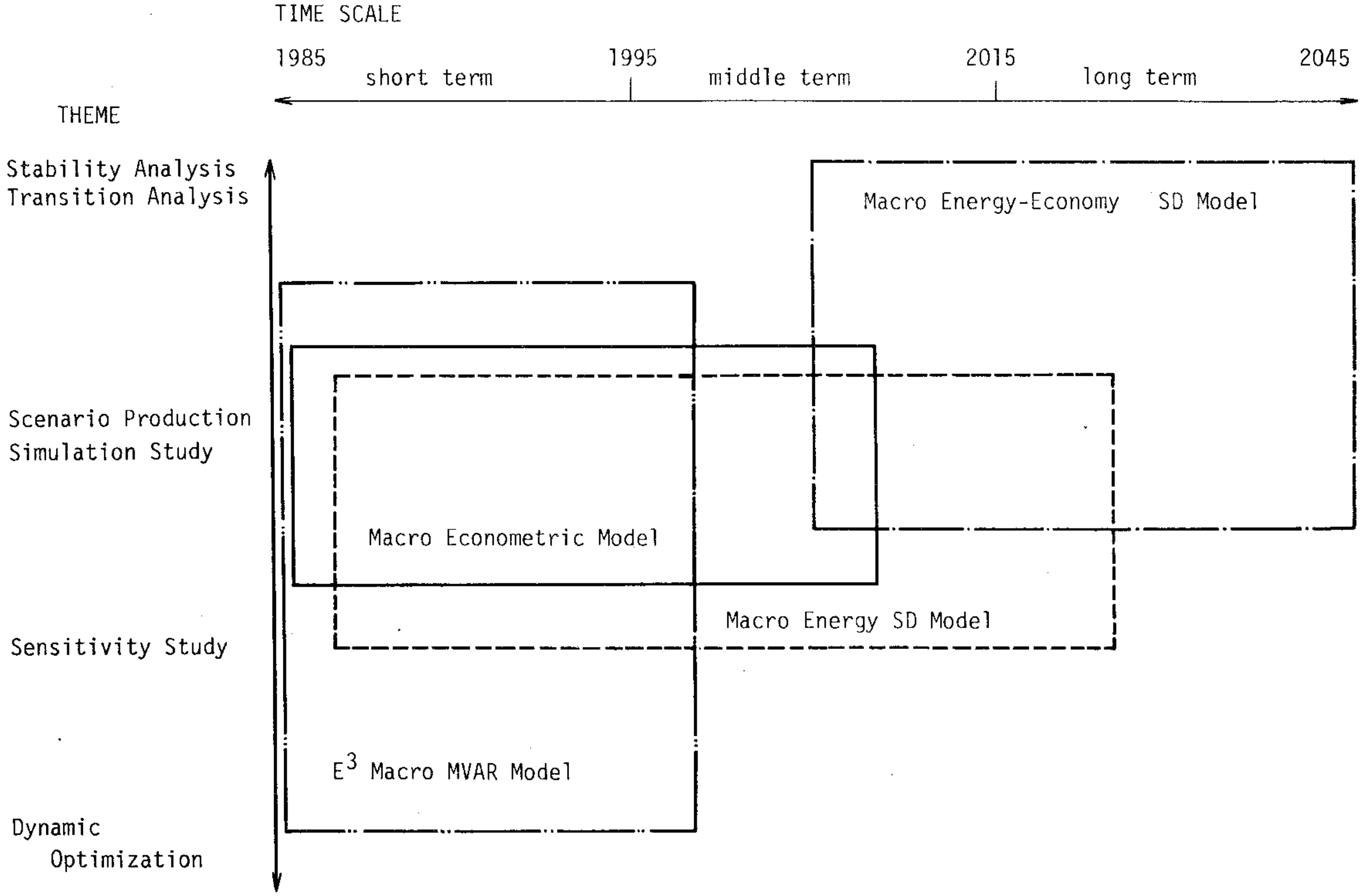


Fig. 2.1.1 Theme and time scale of Macro-SD Model group.

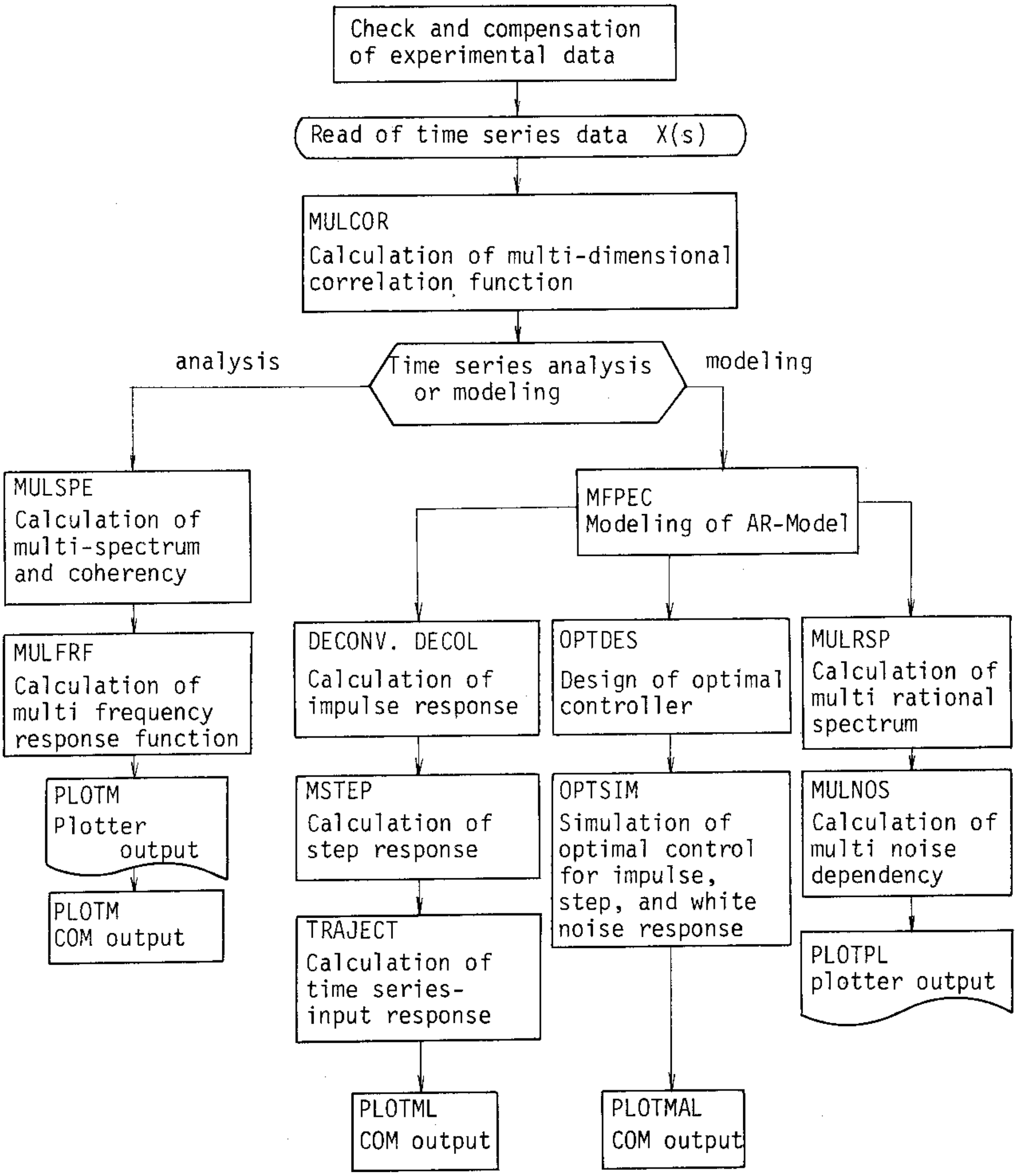


Fig. 2.1.2 The structure of program code for E^3-Macro MVAR Model

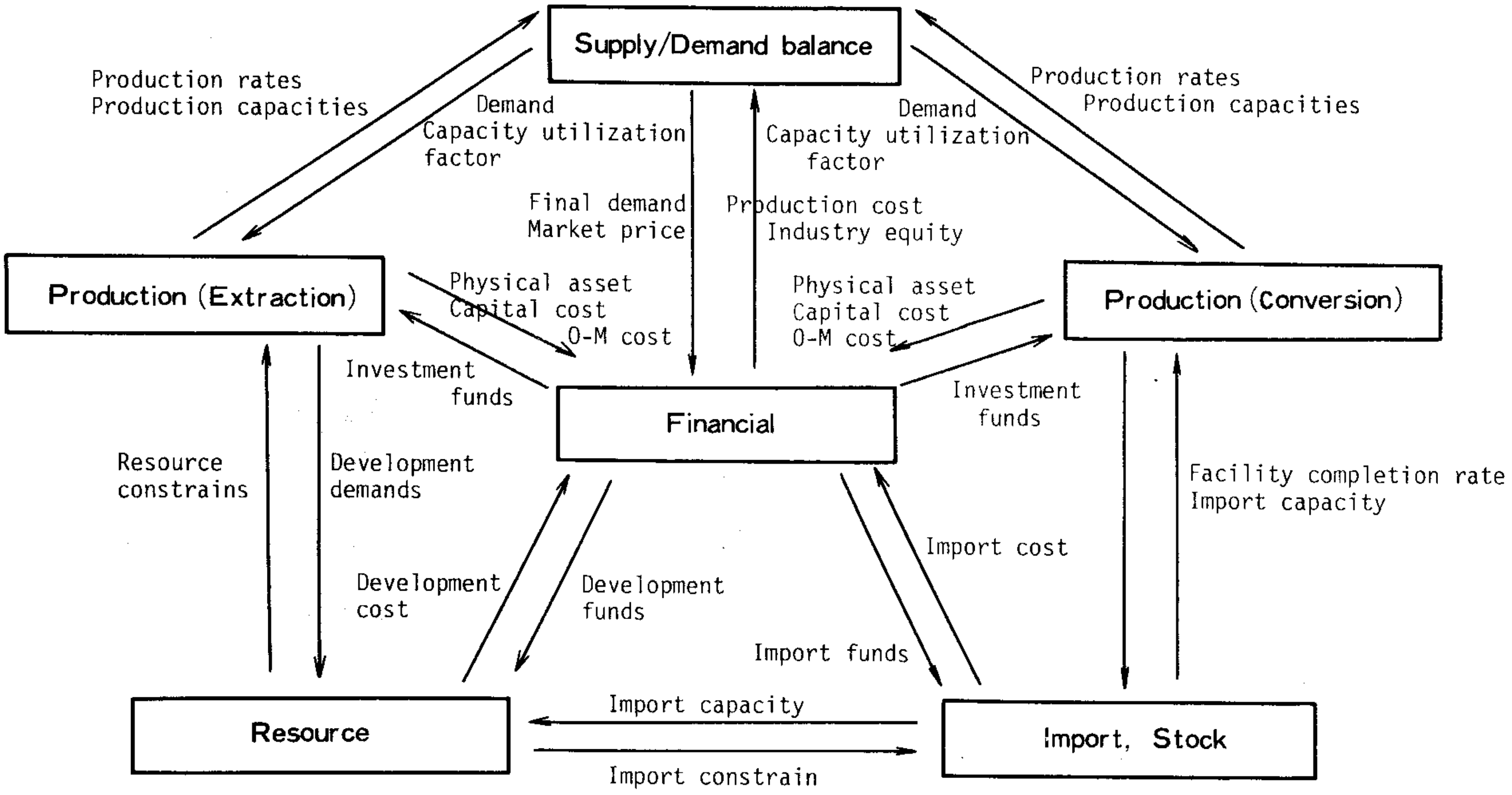


Fig. 2.1.3 Basic structure of Macro Energy SD Model

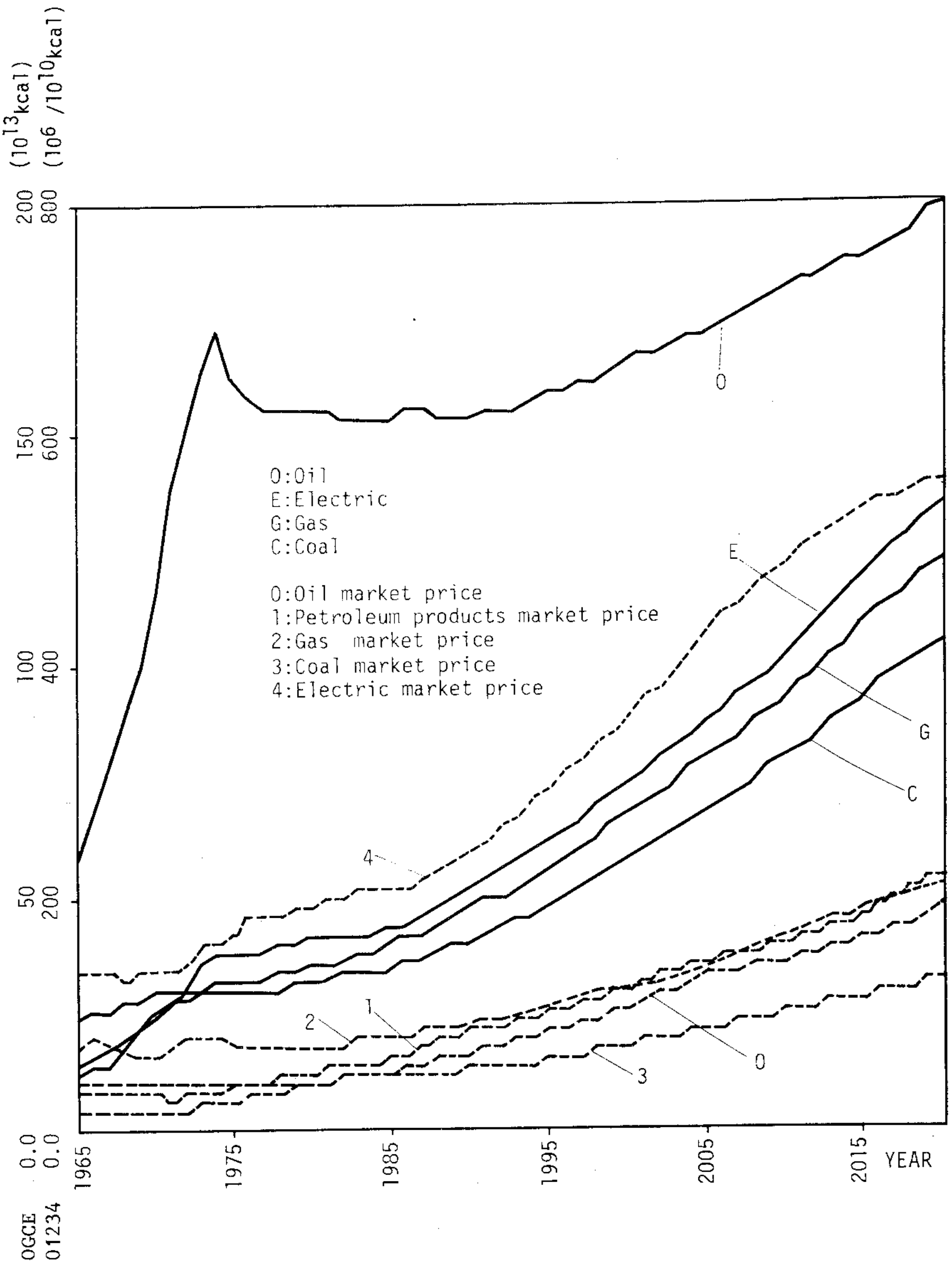


Fig. 2.1.4 Example of estimation by Macro-Energy SD Model.
Final energy consumption and average market price.

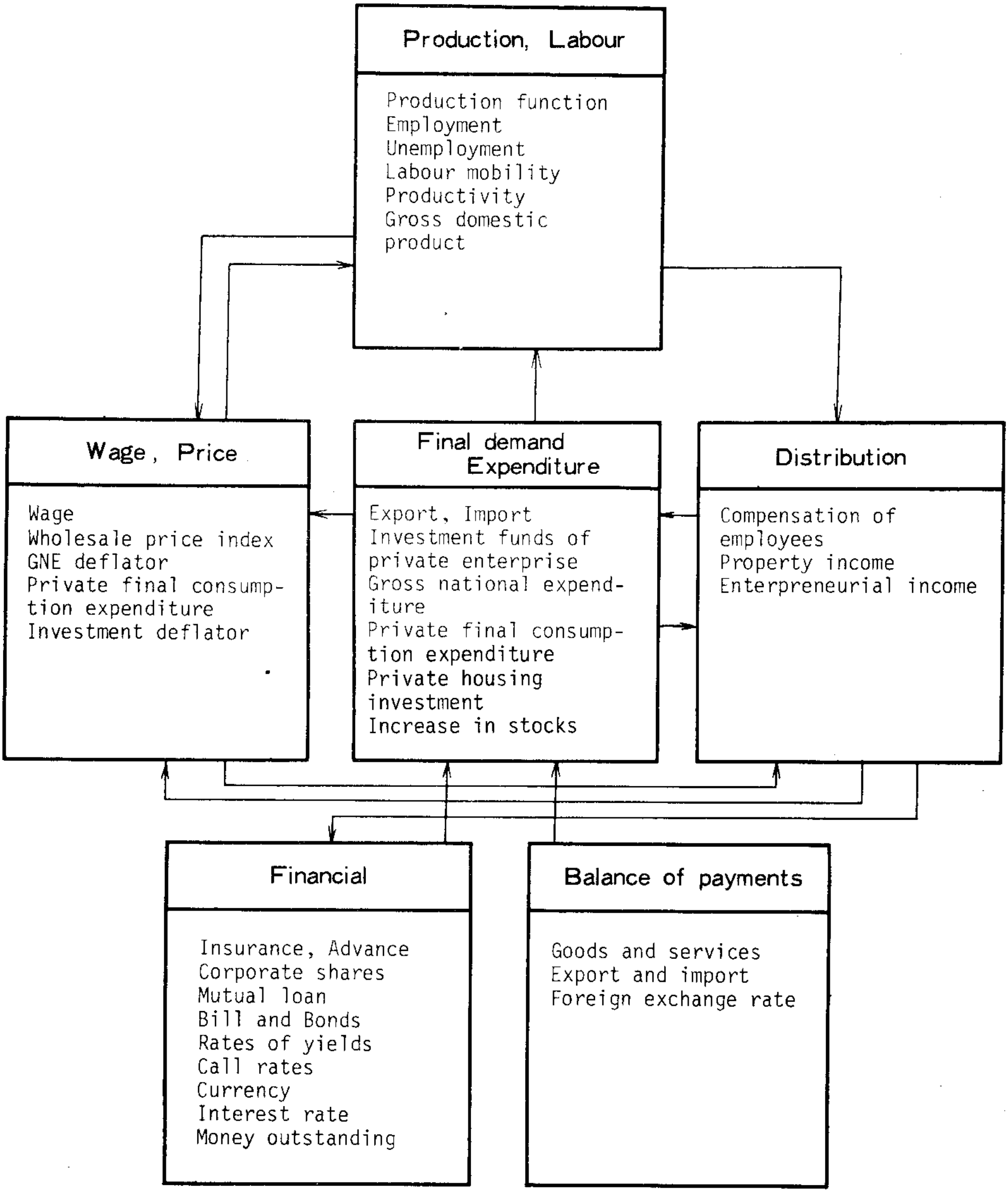


Fig. 2.1.5 Basic structure of Macro Econometric Model

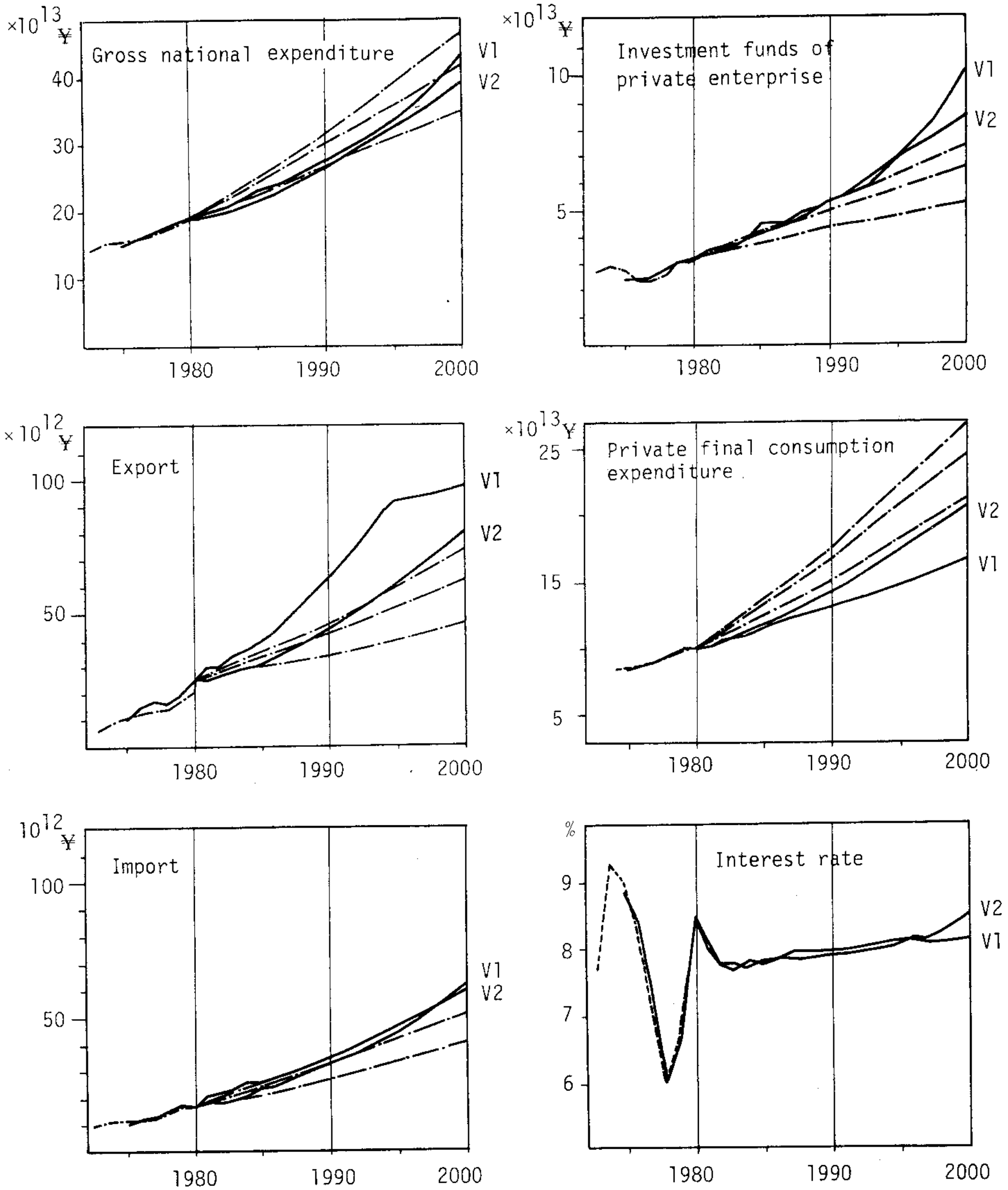


Fig.2.1.6 Example of estimation by Macro-econometric Model. Projection of main macroeconomy indices.

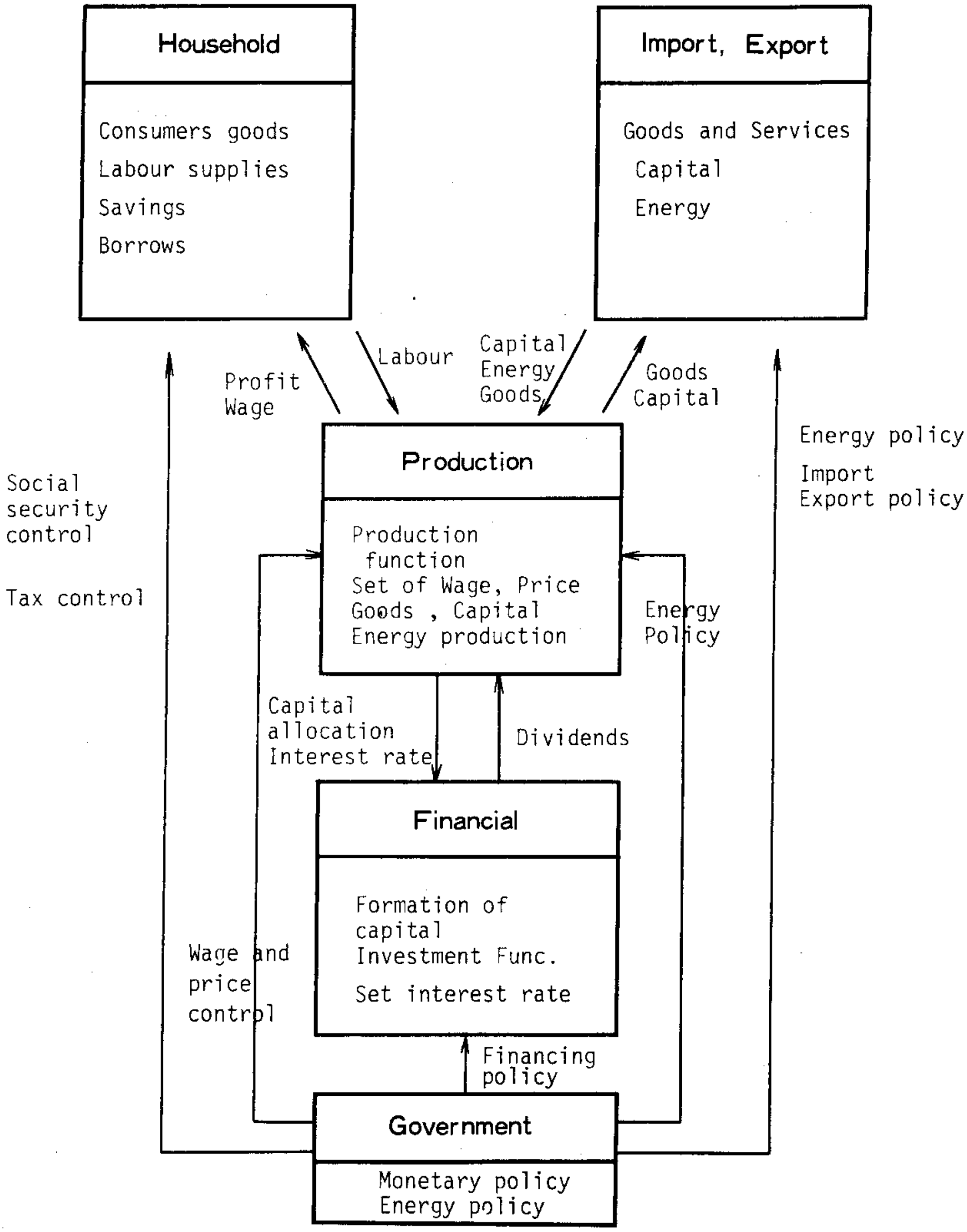


Fig. 2.1.7 Basic structure of Macro Energy-Economy SD Model

Output Input	Non-Energy Industry (23 sub-sectors)	Energy Industry (4 sub-sectors)	Final Demand (8 sub-sectors)
Non-Energy Industry (23 sub sectors)	X_{1j} $\vdots$ X_{ij} $\vdots$ X_{23j}	X_{1E_j} $\vdots$ X_{iE_j} $\vdots$ X_{23E_j}	F_1 $\vdots$ F_i $\vdots$ F_{23}
Energy Industry (4 sub sectors)	Coal X_{E_1j}	$X_{E_1E_j}$	F_{E_1}
	Oil X_{E_2j}	$X_{E_2E_j}$	F_{E_2}
	Gas X_{E_3j}	$X_{E_3E_j}$	F_{E_3}
	Elec. & Heat X_{E_4j}	$X_{E_4E_j}$	F_{E_4}
Non-Energy Industry (4 coarse sectors)	Live. X_{M_1j}	$X_{M_1E_j}$	F_{M_1}
	Mate. X_{M_2j}	$X_{M_2E_j}$	F_{M_2}
	Manu. X_{M_3j}	$X_{M_3E_j}$	F_{M_3}
	Serv. X_{M_4j}	$X_{M_4E_j}$	F_{M_4}
Non-Energy Ind. Total	X_{Mj}	X_{ME_j}	F_M
Energy Ind. Total	X_{Ej}	X_{EE_j}	F_E
Capital Input	X_{Kj}	X_{KE_j}	
Labor Input	X_{Lj}	X_{LE_j}	

Fig. 2.2.1 Accounting framework for industrial transactions

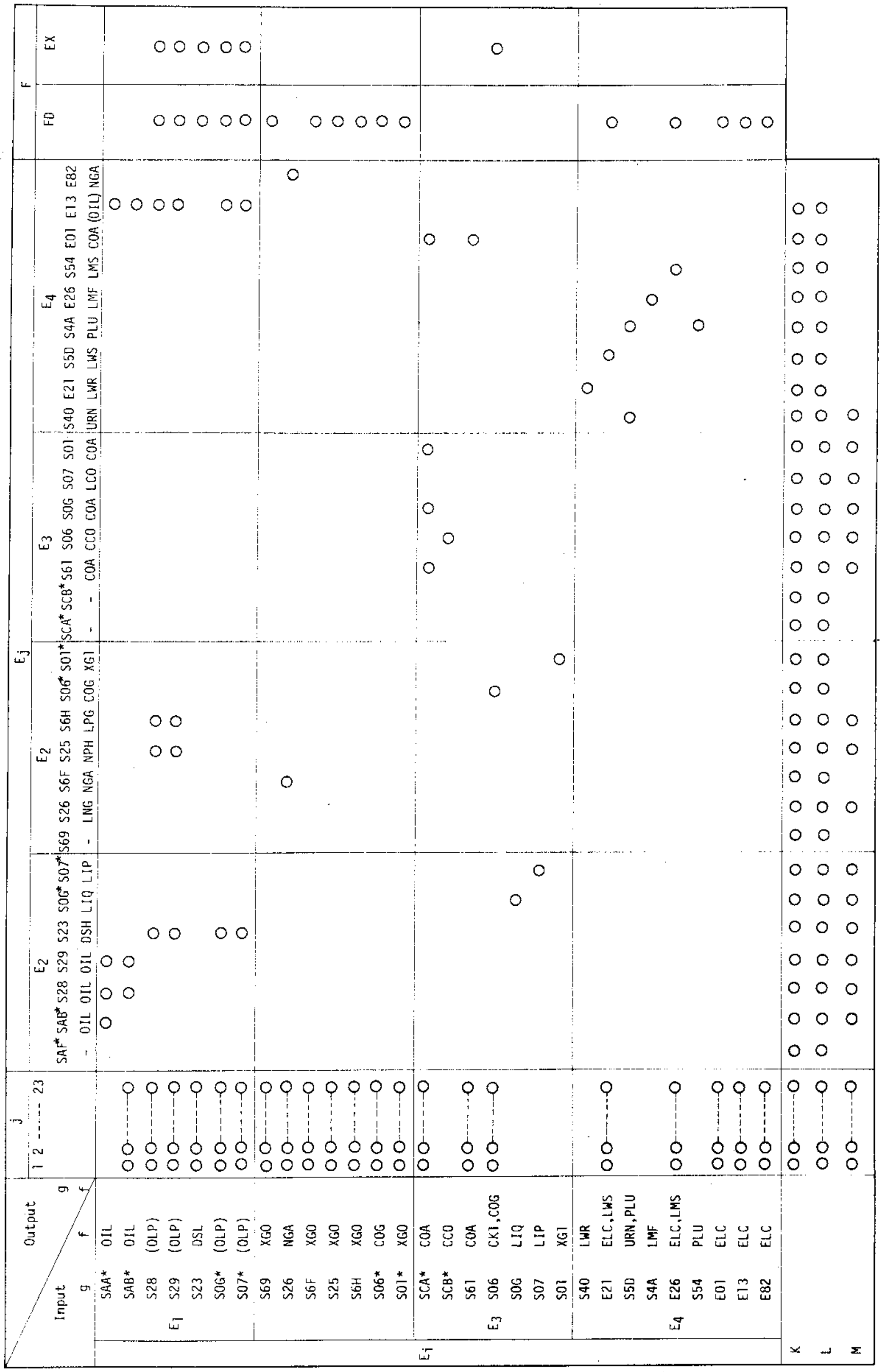


Fig. 2.2.2 An example of sectoral classification and involved energy technology for energy industry sector

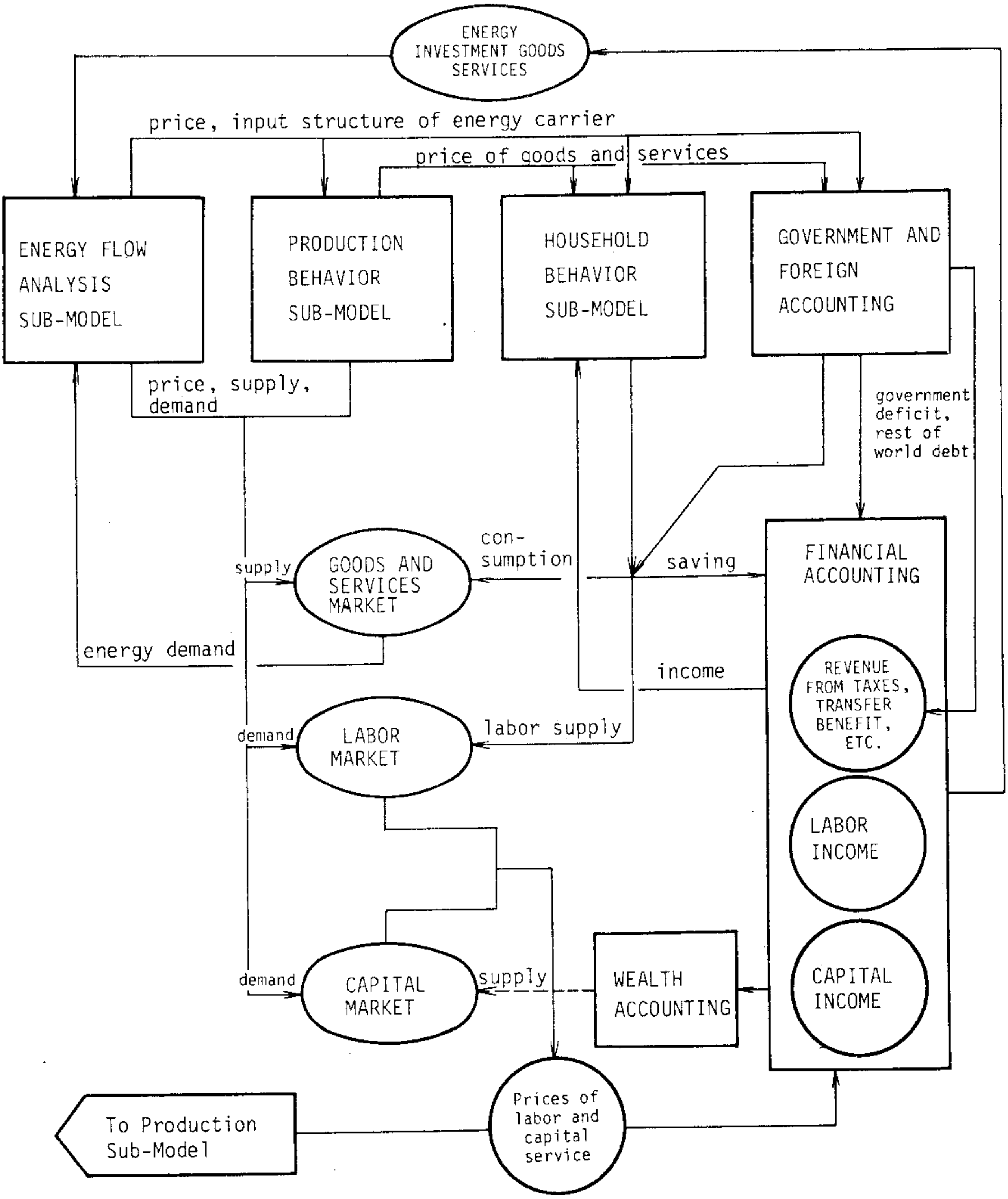
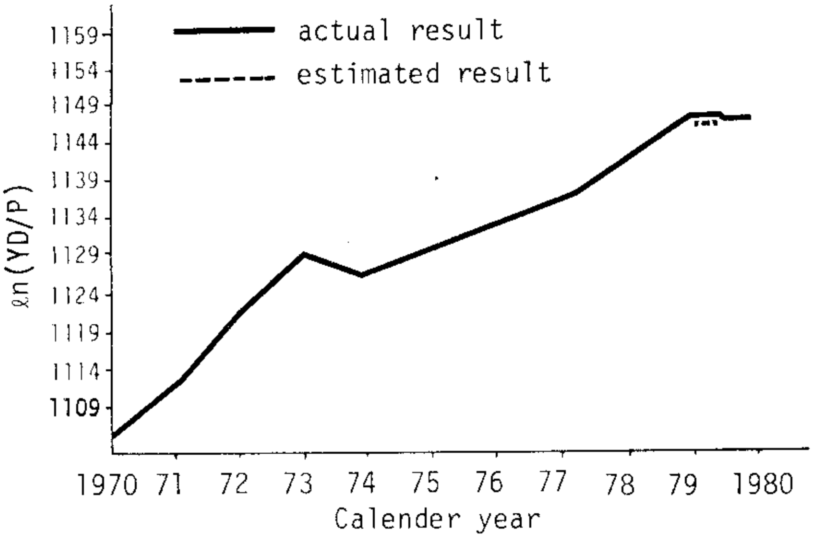


Fig. 2.2.3 Block base representation of energy-economy interaction model

(1) Private Consumption Expenditure YD

L(YD/P)	L(W-/P)	L(D-/P-)	dPC*LYP	CONS	R/SE	D/DF
0.7712	0.1564	0.2104	-0.0197	-1.9072	0.9987	3.567
12.2709	5.7969	3.6896	-6.9480	-3.8142	0.0048	6.000



(2) Leisure Demand LJ

L(LJ/P)	L(W-/P)	VA*LYP	CONS	R/SE	D/DF
0.2351	0.9119	-0.0022	10.8011	0.9834	1.6565
14.0541	0.4473	-4.3848	23.6287	0.0053	7.0000

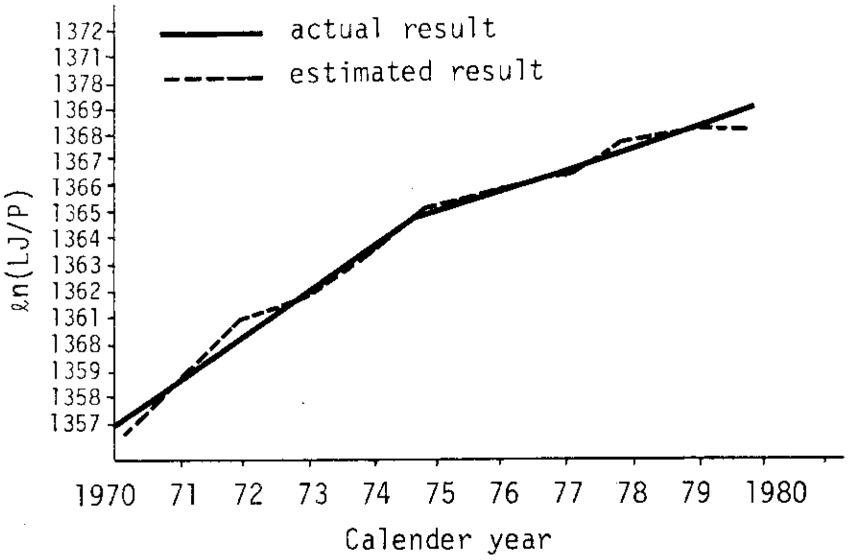


Fig. 2.2.4 Fitting equations of private consumption expenditure and leisure demand made by regression analysis

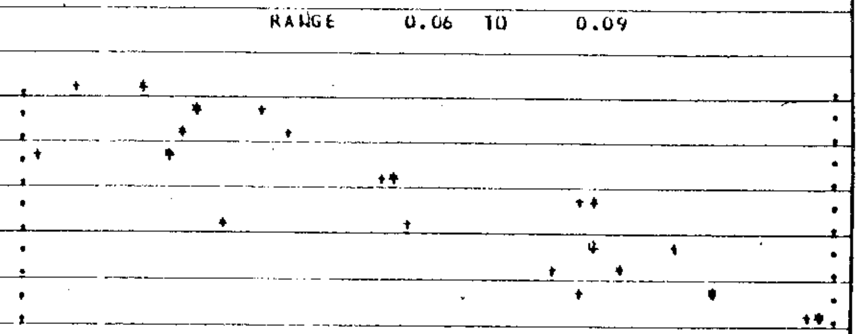
Table 2.2.1 Cost share function $S^{M}_{M'_{kj}}$ for electric machinery sector analized by regression method

```
WM1,12 = (   0.079480)                         (  21.15)
       + (   0.195259) + ALOG(PM1,12)          (   1.68)
       + (  -0.057933) + ALOG(PM2,12)          (   1.11)
       + (  -0.027521) + ALOG(PM3,12)          (   0.56)
       + (  -0.109806) + ALOG(PM4,12)          (   1.49)

  ACTUALS      PREDICTED     RESIDUALS     O/O ERROR

  0.062558     0.059953      0.002605      4.164082   1
  0.064364     0.067180     -0.002816     -4.375422   2
  0.064112     0.068159     -0.004047     -6.311995   3
  0.063576     0.058161      0.005415      8.516663   4
  0.072402     0.071486      0.000915      1.264342   5
  0.079949     0.079480      0.000469      0.586885   6
  0.065665     0.072923     -0.007256    -11.053651   7
  0.079718     0.083225     -0.003508     -4.400041   8
  0.081068     0.078203      0.002865      3.533925   9
  0.084620     0.079549      0.005071      5.993060  10
  0.088749     0.088460      0.000290      0.326267  11

RSQ =     0.830    D.W. =     1.764    WH =   0.00016047
```



```
WM2,12 = (   0.229053)                         (  44.73)
       + (  -0.057933) + ALOG(PM1,12)          (   0.37)
       + (   0.119244) + ALOG(PM2,12)          (   1.68)
       + (   0.020107) + ALOG(PM3,12)          (   0.30)
       + (  -0.081418) + ALOG(PM4,12)          (   0.81)

  ACTUALS      PREDICTED     RESIDUALS     O/O ERROR

  0.259819     0.263843     -0.004024     -1.548737   1
  0.246824     0.239036      0.007788      3.155313   2
  0.237142     0.234424      0.002718      1.145963   3
  0.247812     0.240690      0.007122      2.873755   4
  0.246151     0.243743      0.002408      0.978224   5
  0.220412     0.229053     -0.008641     -3.920520   6
  0.227360     0.225008      0.002353      1.034821   7
  0.214890     0.223569     -0.008680     -4.039165   8
  0.217793     0.217981     -0.000188     -0.086317   9
  0.224481     0.224103      0.000378      0.166580  10
  0.232572     0.233804     -0.001231     -0.529432  11

RSQ =     0.860    D.W. =     2.170    WH =   0.00029798
```

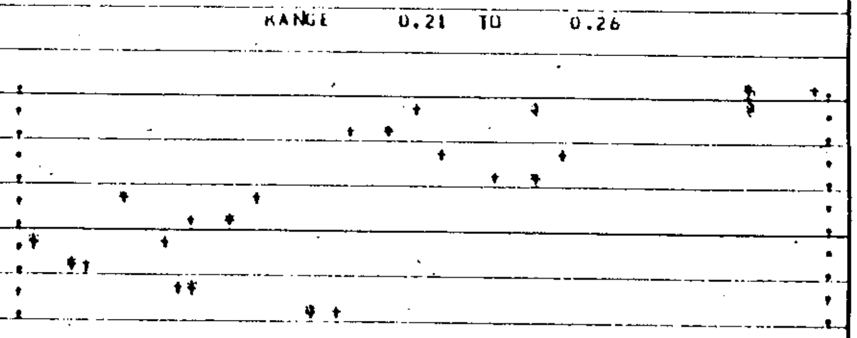


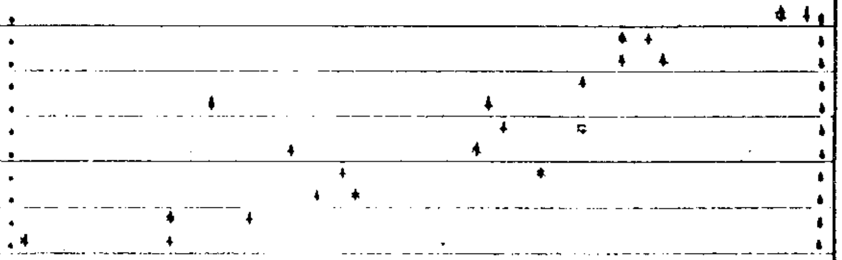
Table 2.2.1 (Continued)

```
WM3.12 = (   0.429238)                    (  47.82)
       + (  -0.027521) * ALUG(PM1.12)     (   0.10)
       + (   0.020107) * ALOG(PM2.12)     (   0.16)
       + (   0.057933) * ALOG(PM3.12)     (   0.49)
       + (  -0.050519) * ALUG(PM4.12)     (   0.29)

  ACTUALS       PREDICTED      RESIDUALS      O/O ERROR                          RANGE     0.40  TO     0.45

  0.448094       0.449865      -0.001771      -0.395237     1
  0.437176       0.438668      -0.001493      -0.341423     2
  0.439890       0.436848       0.003042       0.691478     3
  0.434438       0.434483      -0.000044      -0.010180     4
  0.409205       0.428338      -0.019133      -4.675611     5
  0.434691       0.429238       0.005452       1.254302     6
  0.427108       0.414200       0.012908       3.022070     7
  0.431684       0.417959       0.013726       3.179560     8
  0.419211       0.415939       0.003272       0.780471     9
  0.405691       0.411172      -0.005481      -1.351147    10
  0.396064       0.406540      -0.010475      -2.644872    11

RSQ =       0.651     D.W. =      1.382     WW =    0.00091590
```



```
WM4.12 = (   0.262229)                    (  34.14)
       + (  -0.109806) * ALUG(PM1.12)     (   0.46)
       + (  -0.081418) * ALUG(PM2.12)     (   0.76)
       + (  -0.050519) * ALUG(PM3.12)     (   0.50)
       + (   0.241743) * ALUG(PM4.12)     (   1.60)

  ACTUALS       PREDICTED      RESIDUALS      O/O ERROR                          RANGE     0.23  TO     0.29

  0.229529       0.226339       0.003190       1.389809     1
  0.251636       0.255115      -0.003479      -1.382504     2
  0.258656       0.260569      -0.001712      -0.661472     3
  0.254174       0.266665      -0.012491      -4.914514     4
  0.272241       0.256432       0.015810       5.807326     5
  0.264948       0.262229       0.002720       1.026458     6
  0.279867       0.287868      -0.008002      -2.859106     7
  0.273708       0.275246      -0.001538      -0.561083     8
  0.281928       0.287876      -0.005948      -2.109066     9
  0.285207       0.285175       0.000032       0.011202    10
  0.282614       0.271196       0.011410       4.039989    11

RSQ =       0.770     D.W. =      2.203     WW =    0.00067073
```

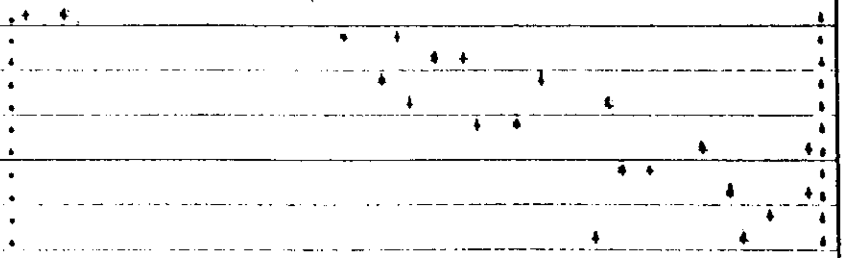


Table 2.2.2 Some examples of capital cost partition coefficient $\theta_j(C^*,INV,g)$ for energy technology g.

I/O Code No.	Basic Sector Classification	Nuclear Power Plant (LWR)	Coal Steam Power Plant	Coal Gassi-fication Plant	Coal Lique-faction Plant	Enrichment Plant(Centrif.)	Enrichment Plant(Diffus.)	Nuclear Fuel Fabric.Plant	Spent Fuel Reproc.Plant
**	*****	**	**	**	**	**	**	**	**
34 3416-010	Steel pipe and tube	4.6	3.4	11.8	9.1	4.3	3.8	-	4.3
37	General machinery	27.7	32.5	39.0	34.9	62.8	61.5	43.0	36.4
3601-100	Prime mover and boiler	13.7	11.7	1.6	2.3	0.1	-	2.0	0.9
3603-300	Chemical machinery	3.8	9.3	28.7	22.0	10.3	18.5	1.2	29.8
3604-110	Pump and compressor	2.8	7.0	5.8	6.9	48.0	35.8	4.7	1.8
3604-120	Conveyor	1.0	1.0	-	0.4	-	-	-	-
3604-140	Refrigerating machinery, etc.	2.5	0.8	2.6	3.3	0.9	6.7	3.1	2.1
3604-190	Other general industrial machinerys	3.9	2.7	0.3	-	3.5	0.5	32.0	1.8
38	Electric machinery and appliances	18.7	13.5	8.8	11.1	8.0	8.4	12.0	13.7
3701-100	Generator	13.3	9.1	0.4	0.9	-	-	-	0.6
3701-200	Transmission and distribution apparatus	2.3	2.5	1.2	2.0	6.0	6.0	2.5	1.8
3701-300	Electric motor	-	-	-	-	-	-	-	-
3701-400	Other industrial strong electrical machinery	-	-	0.4	-	-	-	-	0.6
3703-000	Electronic computer and accessory device	0.5	0.1	1.2	2.2	0.1	2.4	4.2	1.8
3704-100	Other weak electrical appliances	0.1	-	-	-	-		2.0	-
3704-400	Electric measuring instrument	1.1	0.2	4.8	5.0	1.6		2.0	7.7
	Other electric machinery and appliancess	1.4	1.6	0.8	1.0	0.3		1.3	1.2
39 3810-900	Transport equipment		0.1	0.2	-	-	-	-	-
40 3910-600	Precision instruments	0.2	0.2	0.3	-	0.1	-	7.3	0.6
42 4001-003	Building construction	45.2	30.0	35.1	39.6	24.8	26.3	35.9	30.0
43 4004-900	Other construction	3.6	20.3	4.8	5.3			1.8	15.0
**	*****	**	**	**	**	**	**	**	**

Note: (1) Number is in % expression.

(2) Data do not cover whole sectors, but these are consistent within the framework.

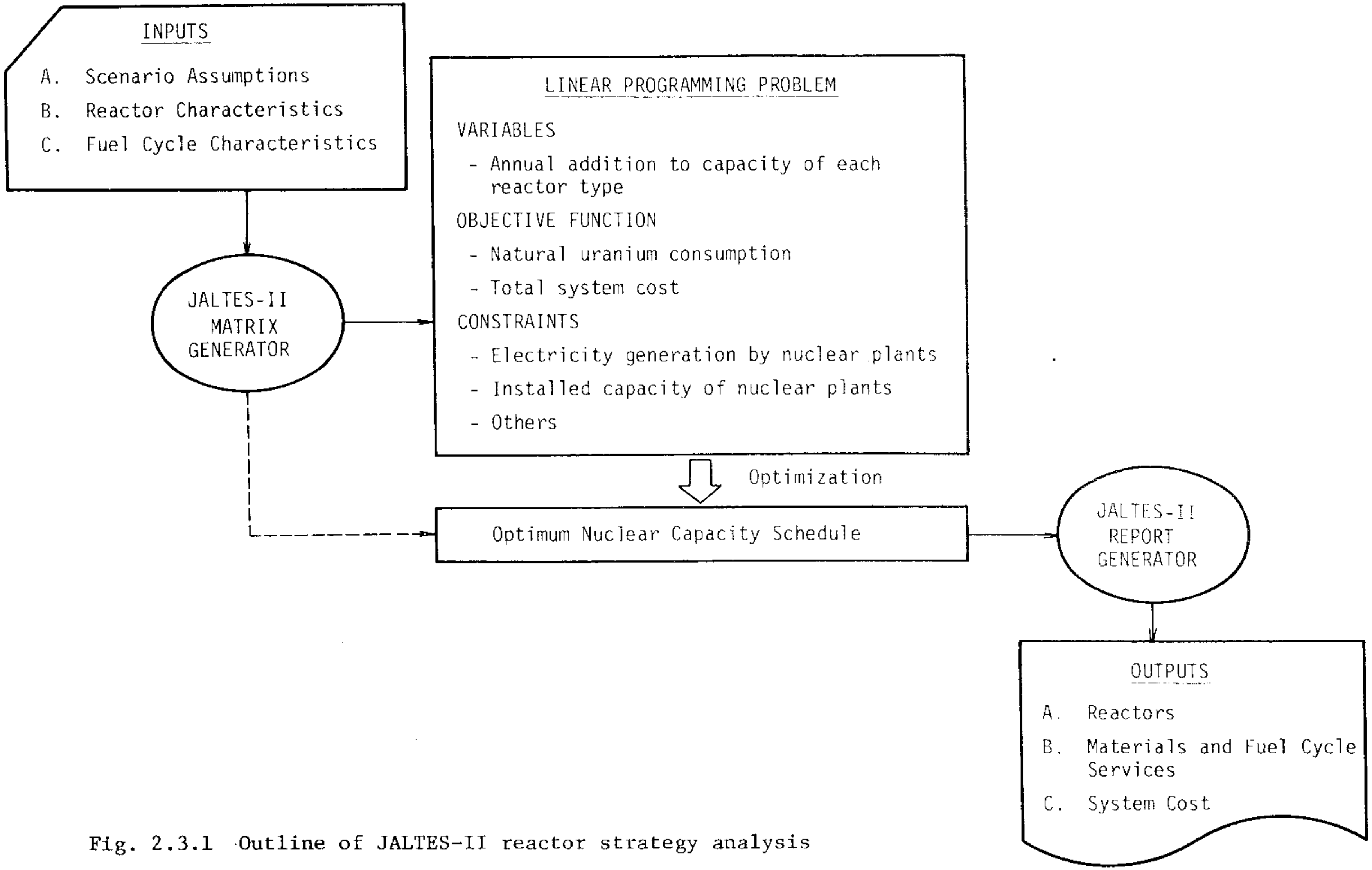
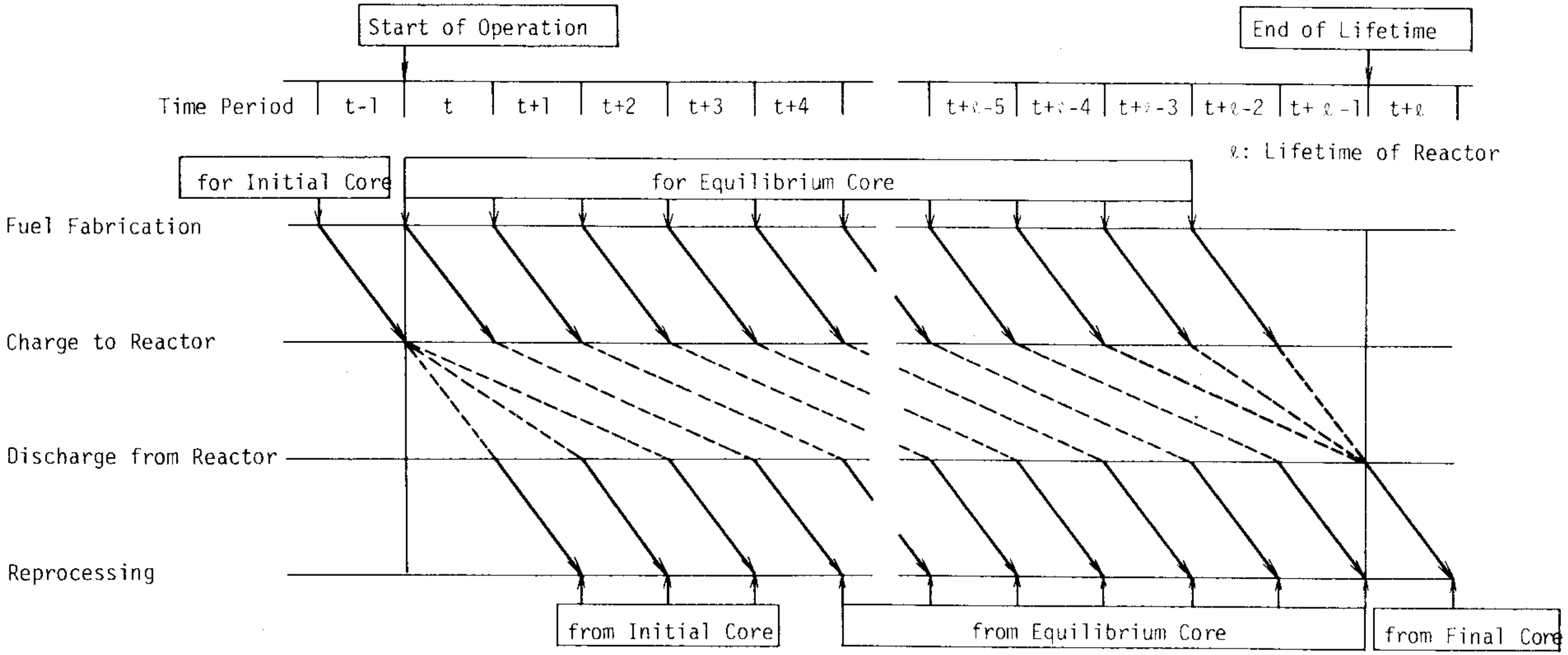


Fig. 2.3.1 Outline of JALTES-II reactor strategy analysis



Assumptions on Time Intervals	Fuel Fabrication - Charge to Reactor	1 Year
	Initial Loading - Initial Discharge	1 Year
	Fuel In-core Dwelling Time	3 Years
	Discharge from Reactor - Reprocessing	1 Year

Fig. 2.3.2 Example of fueling & refueling schedule for a single reactor

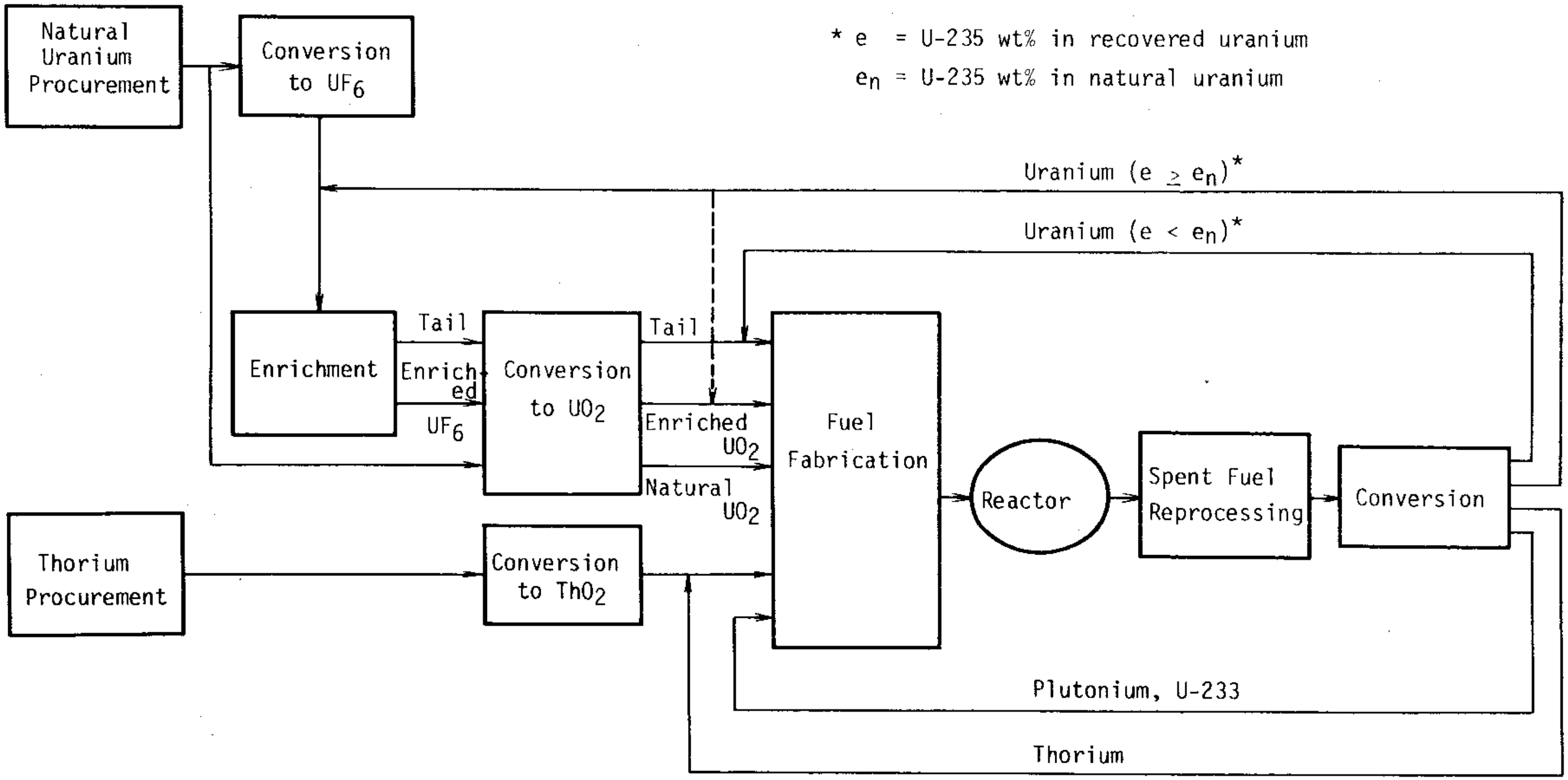
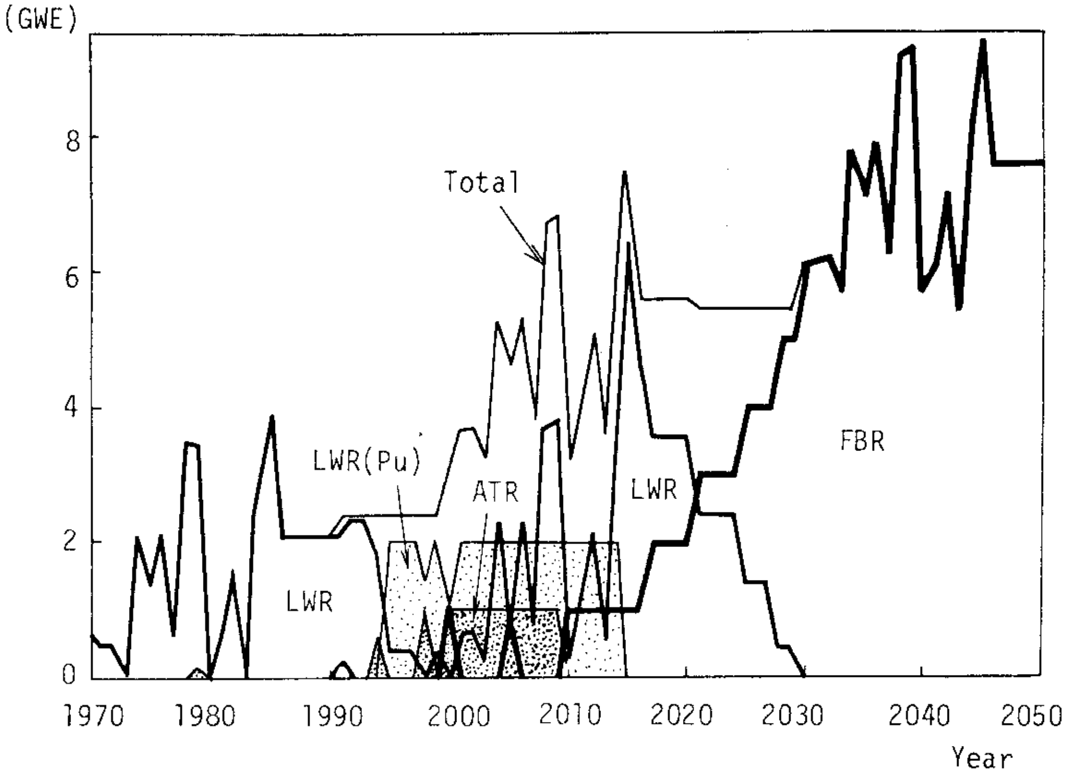
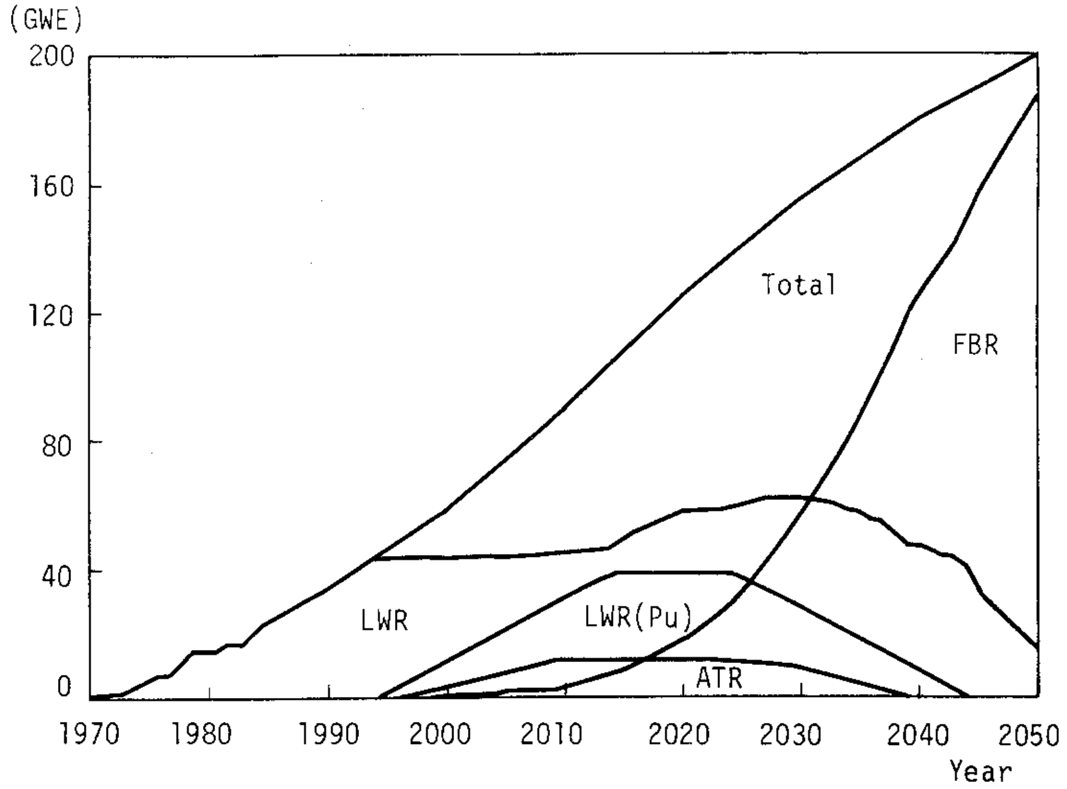


Fig. 2.3.3 Nuclear fuel cycle system in JALTES-II

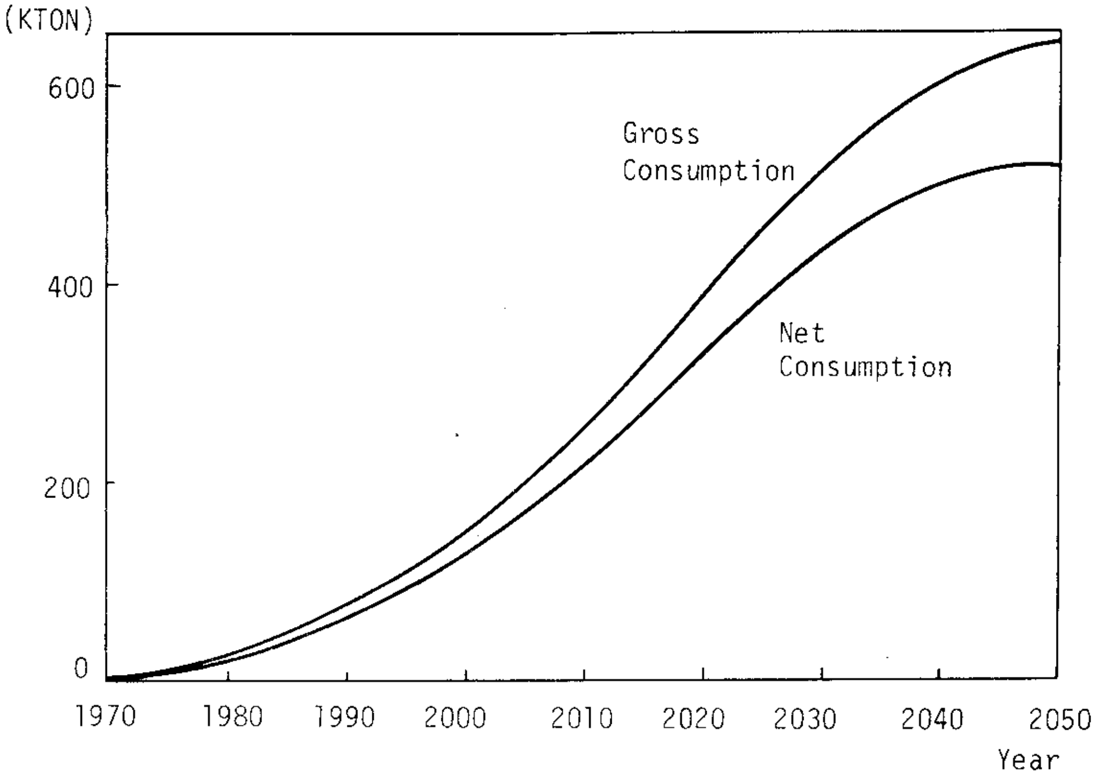


(a) Annual addition to capacity of each reactor type

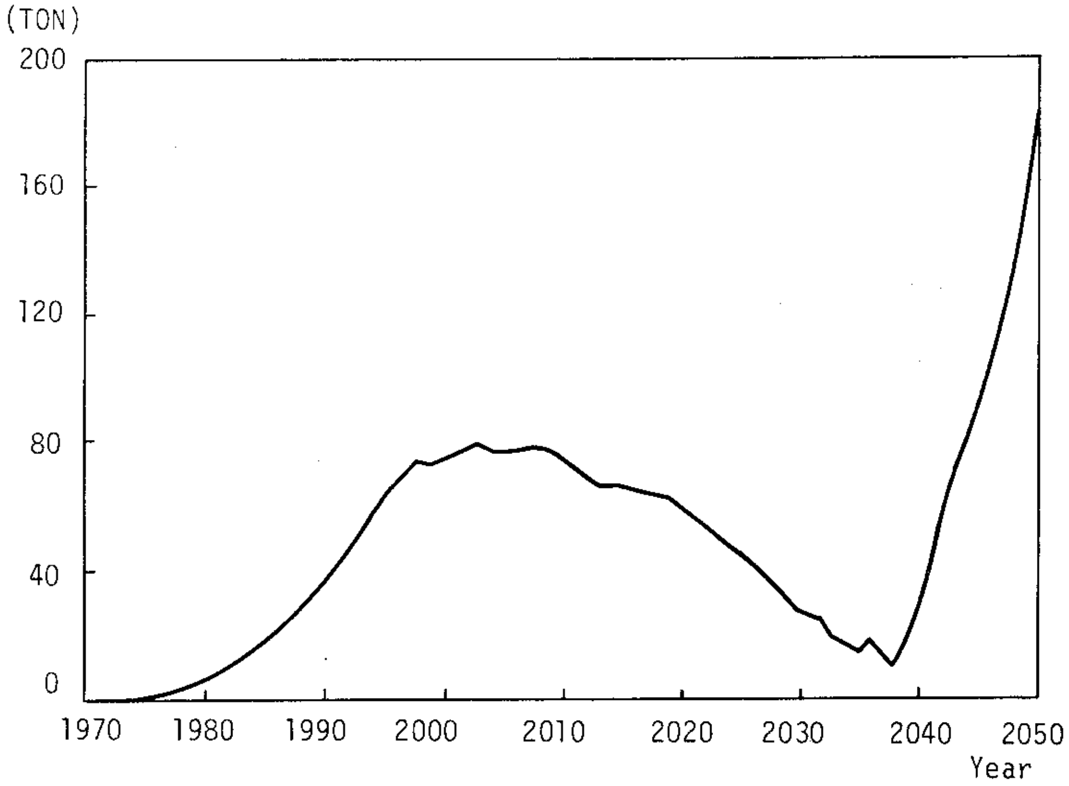


(b) Installed capacity of each reactor type

Fig. 2.3.4 Example of output (1)



(a) Cumulative consumption of natural uranium



(b) Stock of fissile plutonium

Fig. 2.3.5 Example of output (2)

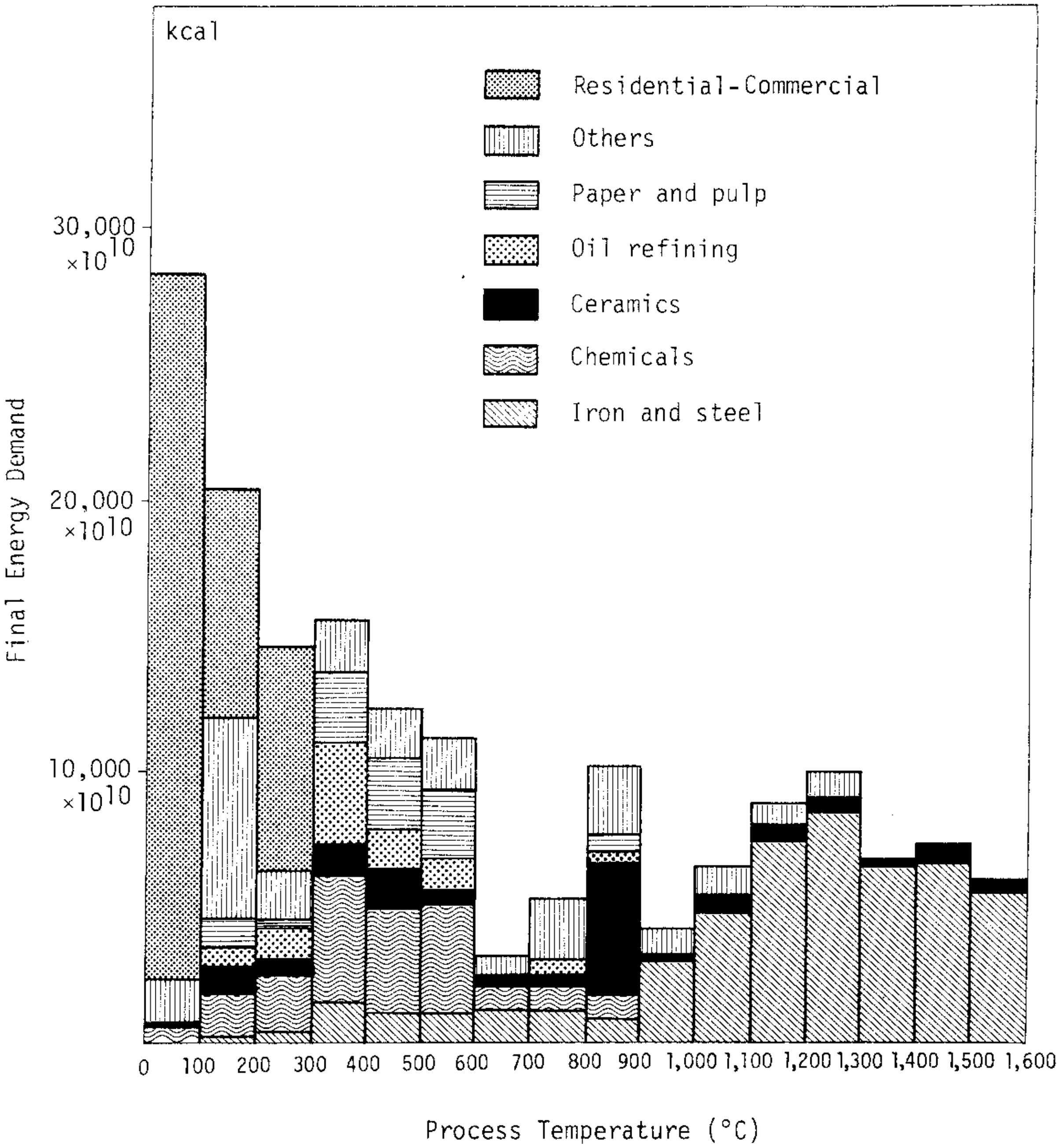


Fig. 2.4.1 Temperature distribution of final energy consumption in 1980

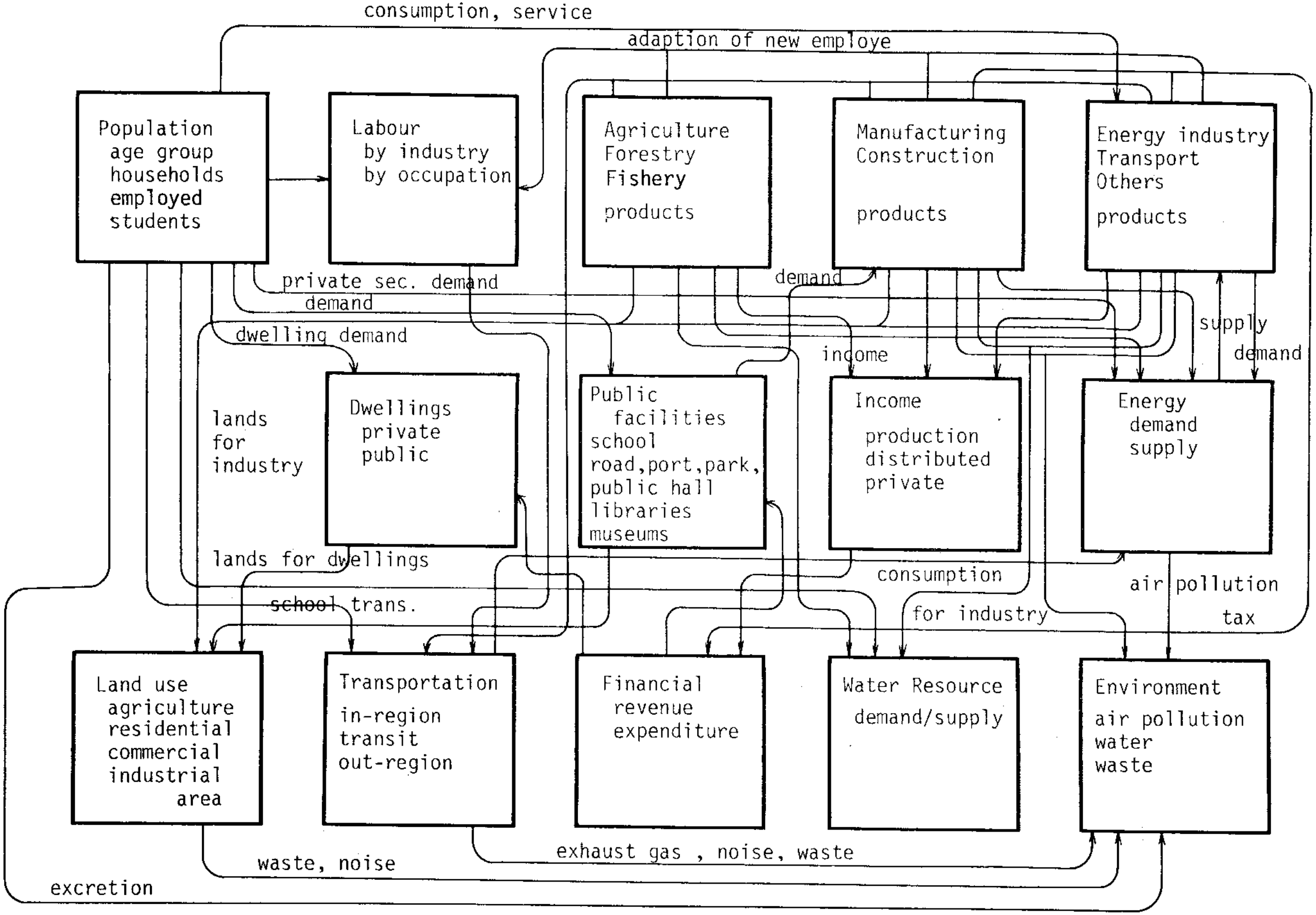


Fig. 2.4.2 Basic structure of Regional Environment Macro SD Model.

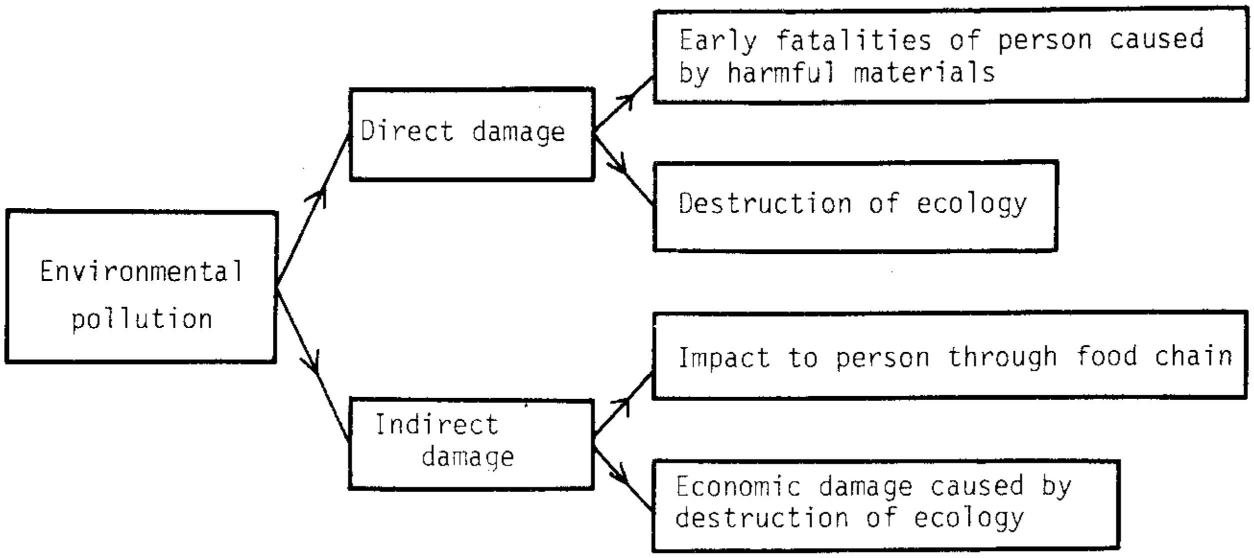


Fig.2.4.3a Environmental pollution and damage

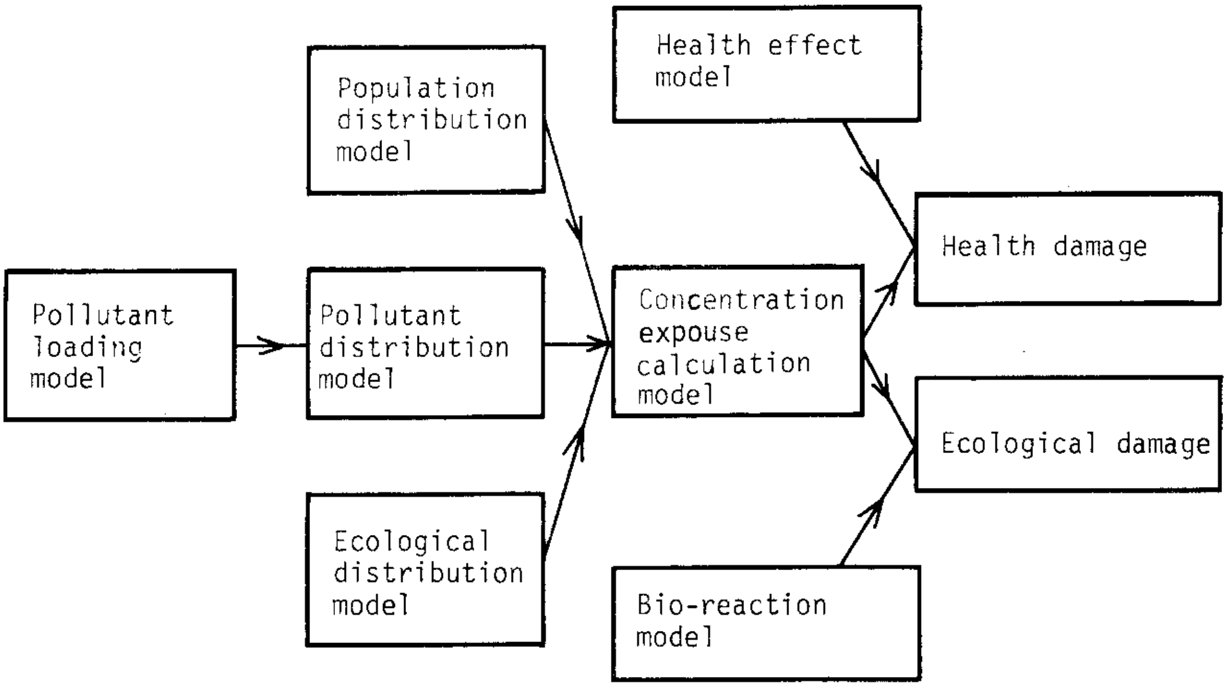


Fig.2.4.3b Impact flow analysis of health and ecological damage.

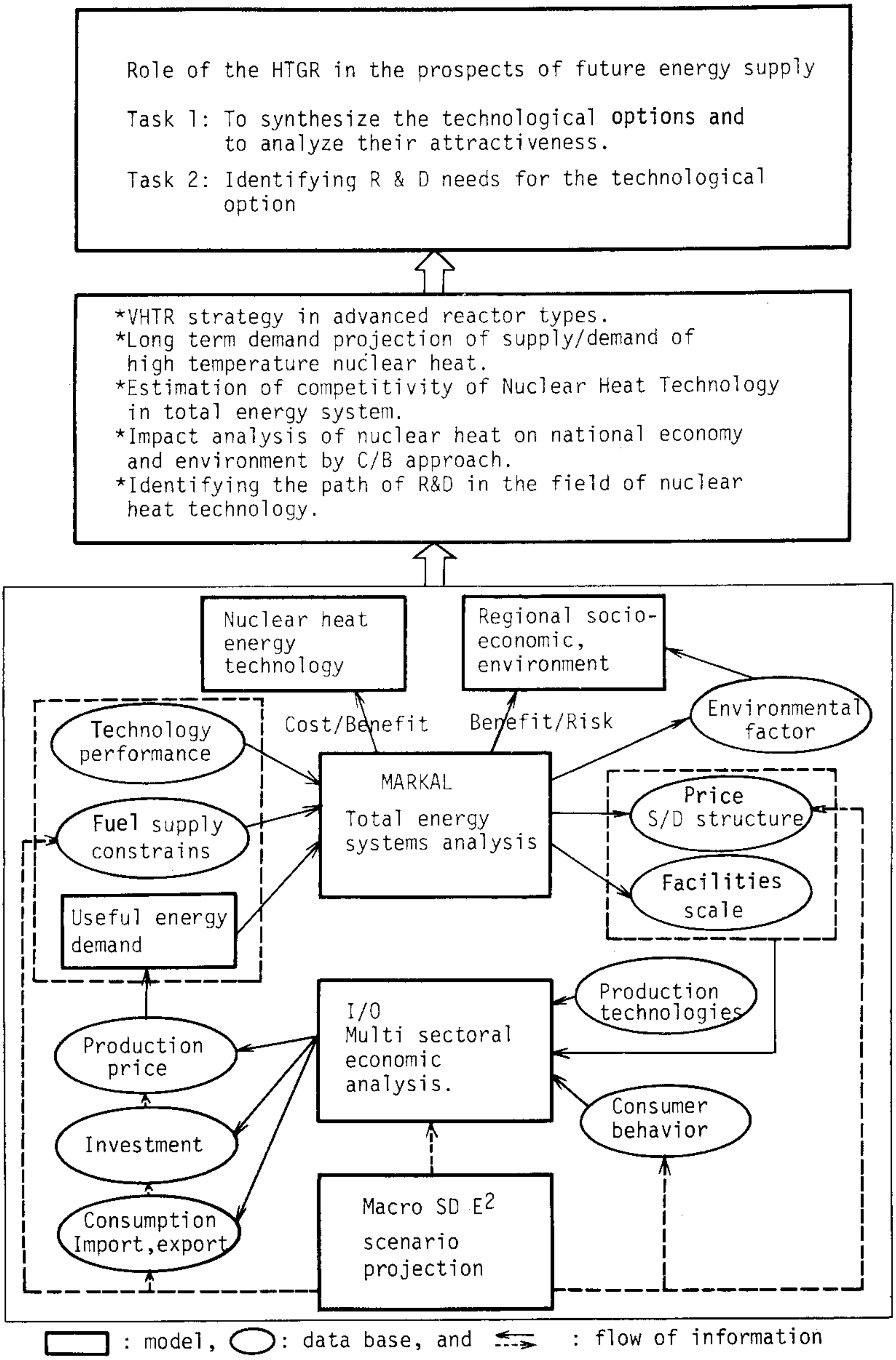


Fig.3.1.1 An example of application for the subject "Role of the VHTR and Nuclear Heat"

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