SIMULATION TECHNIQUES IN ENERGY ANALYSIS

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ABSTRACT. Simulation is one of the most frequently used techniques in energy modelling. After some general remarks on the nature of simulation models, a more detailed description of a large scale dynamic energy simulation model for the Federal Republic of Germany is given. The paper continues with a discussion of some model results and concludes with some brief remarks on the limitations of the simulation approach.

1. INTRODUCTION

The last two decades have seen the emergence of what has come to be known as the "systems approach". The systems approach is a methodology and a practical philosophy of how best to aid a decision maker with complex problems of choice under uncertainty. This approach, at first successful in military and managerial contexts, has now become widely used in many fields, and energy policy and planning are no exception. An important step in the systems approach is the development of models, using them as an appropriate framework for searching out objectives and alternatives, and comparing them in the light of their consequences. Model building is one way to understand complex relationships within a system. A model is always a simplified reflection of reality and can be conceptually regarded as a substitute for the real system. It is used to capture the functional essence of the complex problem under investigation, but not necessarily the detail of the

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whole real system. A model permits experimentation among alternative policy strategies and can illuminate their consequences. To the extent that the model is an appropriate representation of the system and problem to be analysed, it can be a valuable aid to policy analysis and policy making.

In view of these potential benefits, it is not surprising that during recent years there has been growing interest in using models to help plan our way out of the energy problem facing mankind today. The International Institute of Applied Systems Analysis has published a set of very useful review reports of energy models [1].

The 144 models analysed and classified so far range in scope from models for a single fuel to those of the whole energy supply system. They include models related to the energy and economy interactions, on a national as well as on an international scale.

A variety of methodologies are used in the different models. Most employed are econometric methods, simulation, linear programming, and I/O techniques.

Today, there is no common agreed definition of a simulation model. In the following, simulation models are referred to as a special class of mathematical models which express the dynamic relationships among the variables and parameters of the system modelled. Running a simulation model results in the calculation of changes in the state of the system through time.

Simulation models are dynamic models. Simulation models may be classified as predictive models; while they help to answer questions of the type, "What will happen, if...?", whereas optimization models belong to the class of normative models answering questions of the type, "What should be done, in order to achieve a desired goal?". Within the class of simulation models usually a distinction is made between "deterministic" and "probabilistic" models. In deterministic models it is assumed that the exact values of all variables can be computed, whereas in a probabilistic model, at least some variables have an unpredictable randomness, and must be represented by a probability distribution.

During the last few years a number of special purpose simulation languages have been developed. These languages are generally thought of as easier to learn and apply, by simplifying the programming of simulation models. However, special purpose simulation languages have somewhat limited flexibility and range of application compared with general programming languages such as FORTRAN.

After these more general and methodological remarks on simulation models, we will in the following describe in some detail a simulation model of the energy system of the Federal Republic of Germany.

2. A DYNAMIC ENERGY SIMULATION FOR THE FEDERAL REPUBLIC OF GERMANY

During the last years the Programme Group of Systems Analysis and Technological Development of the Nuclear Research Center in Jülich (FRG) has developed a dynamic energy simulation model called LESS* [2-7] to be used as a flexible tool in analysing important issues for the development of the energy system of the FRG. The long term energy simulation system (LESS) is part of a large energy model system (JES: Jülich Energy-model System) (Fig. 1) which consists of a set of different energy and energy related models, a data base, and a method base for linear and nonlinear regression and correlation analyses [8,9].

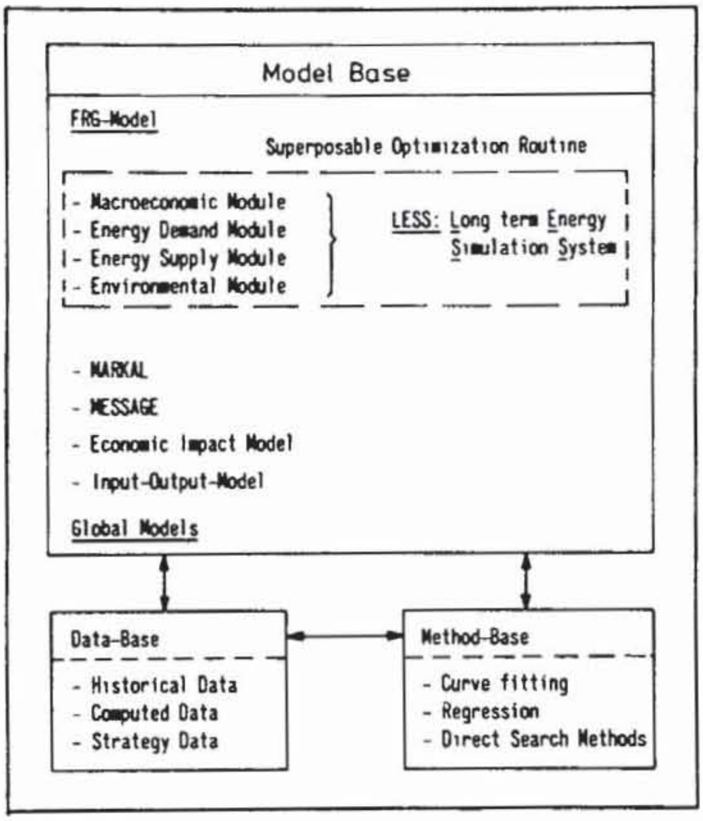

FIGURE 1 - JES-Jülich energy-model system

LESS consists of four modules

- a macroeconomic module,
- an energy demand module,
- an energy supply module, and
- an environmental module

*LESS - Long term Energy Simulation System which are interconnected by input and output flows as outlined in Fig. 2. The structure of the four modules will now be described in more detail.

2.1 The Macroeconomic Module

The reasons for developing a macroeconomic module derive from the fact that the production and utilization of energy is very closely connected with the economic development of a nation. Consequently, future options of the energy demand and supply system cannot be analyzed and modelled independently from the economic forces within the system. They are always based either explicitly or implicitly upon certain economic assumptions, such as GDP, income, or capital allocation. Generally there are two ways of covering the economic impacts within an energy model:

1. by selection of economic scenarios which provide straightforward input to the energy sector alone;

2. by utilization of complete models in which the energy sector interacts with the economic sector.

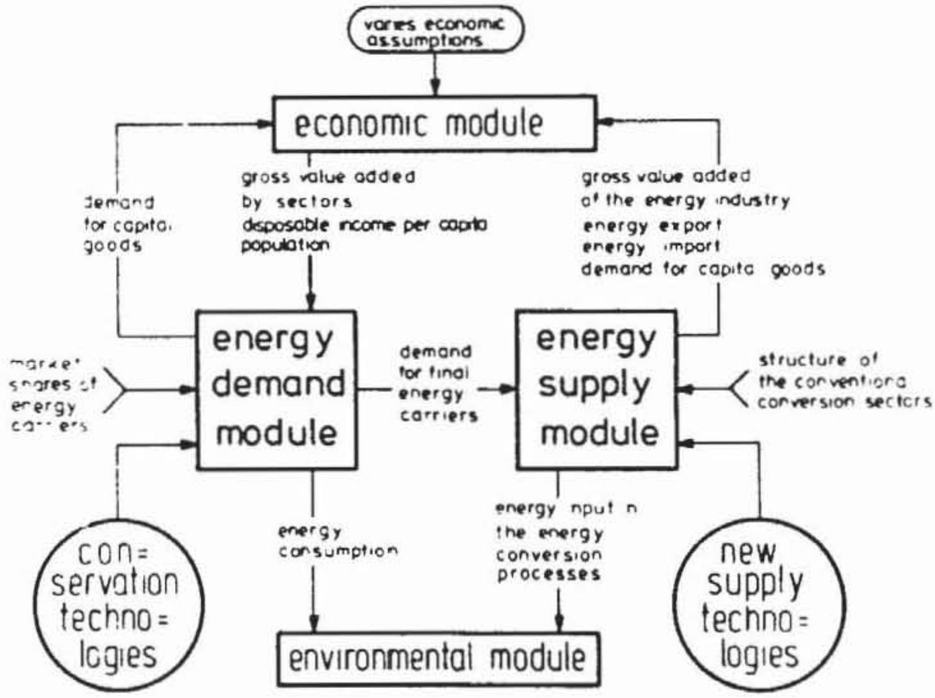

FIGURE 2 - LESS - Long term energy simulation system

LESS makes use of the second approach. A macroeconomic model has been developed which generates the growth in different economic sectors. The sectors have been selected with respect to the energy intensity. They are the four industries (iron and steel production, chemical industries, stone, clay and construction materials, and other industries), the commercial sector and the energy branch. For each branch individually, the growth rate is calculated by means of the allocated production factors (labour and capital), the production outputs and the gross value added. The allocation of production factors is demand driven, i.e. determined endogeneously by intermediate and final demand, but is limited since it depends on a number of constraints such as labour force participation, capital allocation, and intermediate inputs.

In each economic branch, the input of goods which is needed in the production process has to be calculated, as most of these goods have to be produced by the other economic branches. These necessary input goods of a branch are dependent on the production output and on the production structure. In the macroeconomic module, the production structure of a branch is given by technical coefficients, which are the input coefficients of an input-output matrix. As the production structures vary with time, the technical coefficients are also time dependent. With the exception of the coefficients describing the energy input into the branches, these values are estimated exogeneously using input-output matrices and their projections which are available to us but calculated by other institutions. By summing up all input goods, the intermediate demand for the products of each economic branch is obtained.

The components of final demand are determined in the following way. The disposable income of private households is calculated as a function of the gross domestic product, which is the sum of the gross value added of all economic branches. Depending on the development of this disposable income, the consumption of private households is estimated. The collective consumption, that is, the consumption of general government and nonprofit institutions, is given as a function of the gross domestic product. Depending on the development of the production factor capital, the demand for capital goods can be calculated by using a gross-investment matrix. The export of each branch is given as a fraction of its production output. This fraction is an exogeneous value.

Summing up the consumption of private households, the collective consumption, the demand for capital goods and the export, the final demand for the products of each branch is received. The estimation of the primary production factors as mentioned above is dependent on the development of the total demand for goods of the single economic branches, which are calculated as the sum of the intermediate and the final demand. Thus, the economic growth loop is closed.

2.2 The Energy Demand Module

The consumer has a direct requirement for:

- heat,
- light,
- entertainment,
- comfort,
- food,
- transportation,

under the influence of

- economic,
- social, and
- political constraints.

These requirements are transformed to a demand for

- products,
- services, and
- energy.

Therefore it is necessary to distinguish between a direct and an indirect energy demand. From the viewpoint of the final consumer, for example, the energy for space heating marks the direct energy demand, while energy to build the radiators, the boilers etc., is considered as an indirect energy demand.

In a long term view of the industrial sector, the indirect energy demand for building the radiators and boilers equals the direct energy demand for industry.

Starting from the needs of the consumers, we can differentiate between:

- basic energy demand with respect to an applied technical system,
- final energy demand,
- secondary energy demand,
- primary energy demand.

Within the energy demand module, the final energy demand in different sectors is determined by the demand of energy services, e.g. the hot water demand in the residential sector, the persons or goods transport volume in the transport sector, or the production of steel in the iron and steel industry. This is achieved via economic indicators such as the personal disposable income, and the gross value added of the different economic branches. The final energy is determined for the following sectors:

- the industry (with four industrial sectors corresponding to those in the macroeconomic module),
- the transport sector, in which the four transportation media - road, rail, water, and air - are distinguished.
- the residential sector, in which the energy demand for the three purposes - space heating, water heating, and others - are considered.
- the petrochemical sector (with its socalled nonenergetic energy consumption).

Fig. 3 shows in some more detail the structure of the transport sector as represented in the model. A distinction is made between goods and passenger transport and the different transport modes. The specific energy consumption of the different transportation systems together with their share of the overall transport volume is used to determine the final energy demand by energy carrier of the transport sector.

It should be mentioned that the module allows the computation of the energy savings by introducing energy conservation technologies like:

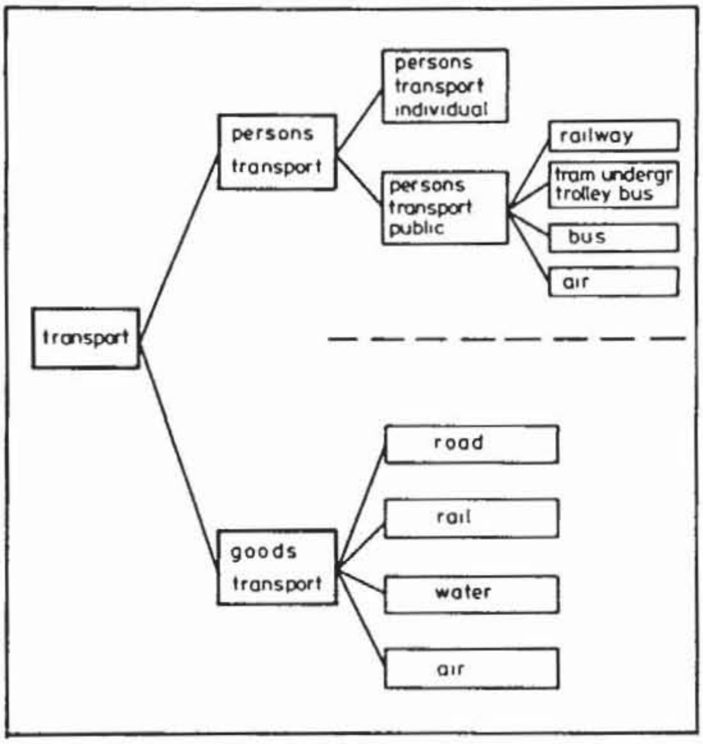

FIGURE 3 - Structure of the transport sector

- better insulation of buildings,
- heat pumps, and
- solar room heating systems.

The output of the energy demand module, i.e. the final energy demand by energy carriers, provides the input for the energy supply module.

2.3. The Energy Supply Module

The energy supply module has two tasks:

1. to calculate the primary energy used to meet the final energy demand,

2. to feedback the employees, the net production and the investments within the energy sector to the macroeconomic module.

For calculating the primary energy consumption, a demand orientated flow model of the mining and conversion processes has been built up. Fourteen energy carriers are balanced with the equation:

$$IP + IM - EX - BU + ST = PC = FC + NC + DL + IT + OT + CT$$

From left to right the following items are taken into account:

Indigenous production (IP) e.g. mining or pit gas, imports (IM), exports (EX), bunkering (BU), and changes in stockpiling (ST), on the left hand side of the primary energy consumption (PC), final energy consumption (FC), nonenergetic fuel consumption (NC), i.e. petrochemical consumption, distribution losses (DL), inputs (IT), and outputs (OT) of all conversion processes and consumption by the energy branch itself (CT), i.e. the self consumption, on the right hand side.

Four mining processes (hard coal, lignite, crude oil, natural gas) and 21 conventional and new conversion processes are considered. The conventional ones are cokeries, gasworks, blast furnaces, conventional steam power plants, light water reactors, and heat production and refineries.

The following new technologies are taken into account: high temperature reactors, fast breeder reactors, and windpower stations for electricity generation; methanol production, gasification of lignite and hard coal in each case, using the conventional methods as well as the processes based on nuclear process heat from HTRs; autothermal coal liquefaction, hard coal combined cycle plants; and, finally, electrolytic and nuclear thermochemical hydrogen production, primarily to meet the hydrogen demand of the iron and steel industry when shifting from conventional steel production to direct reduction of iron.

Each process is mainly characterized by its energy output broken down to the different energy carriers, the inputs, and the self consumption. For the primary energy carriers, the total demand, that means the final demand plus input into transformation processes, plus consumption of the energy sector plus distribution losses plus bunkers, determines the mining up to an upper limit and the net imports as a remainder. For the secondary energy carriers, the total demand and the net imports determine the output of one single, or by market shares the output of two or more, alternative transformation processes, the outputs from other transformation processes being substracted.

The reserve situation, the maximum of production capacity and a share of primary energy consumption which should be covered by indigenous production, determine the gross production. After substracting the self consumption, the available quantity of crude oil and natural gas are computed. Fig. 4 describes the production of crude oil and natural gas.

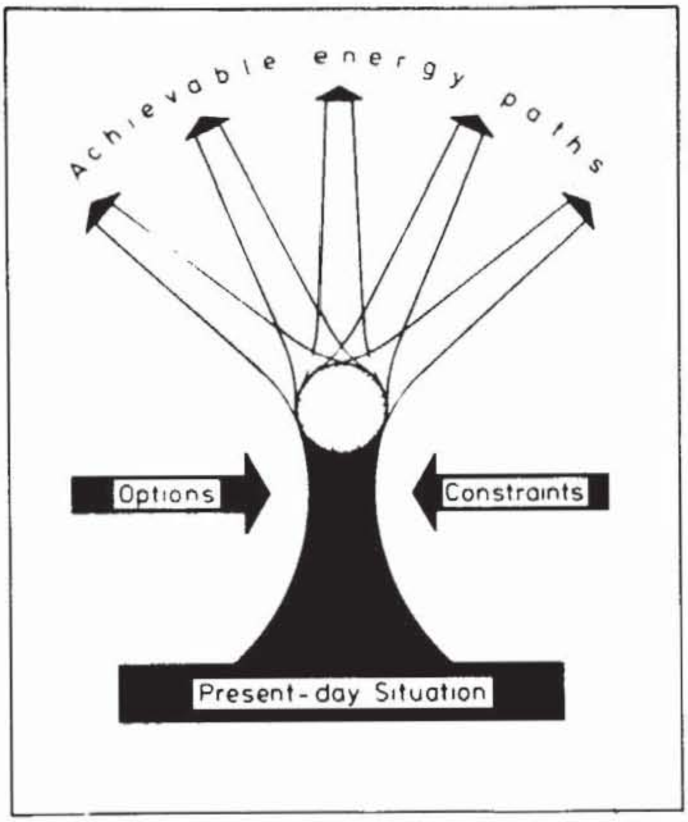

FIGURE 4 - Working out "hard" decisions

As mentioned before, the second task of the energy supply module is the calculation of the number of employees, the gross value added, and the investments in order to close the loop economic growth - energy demand - energy supply - economic growth. The value of these three factors are coupled in general with the energy output of the different conversion technologies or with the indigenous production in the mining sector.

2.4 The Environmental Module

The environmental module is an emission model, calculating total emissions due to energy consumption and conversion by multiplying the energy inputs with the relevant specific coefficients of emission. The calculation of the annual energy consumption is made in the energy demand and energy supply module. The specific coefficients are exogeneous variables which for the past are derived from statistics, and for the future are either kept constant or changed - in most cases decreased according to different environmental abatement technologies and policies.

3. OPERATION OF THE MODEL

The model system can be operated in two ways:

- in an event-oriented way
- in a decision-oriented way.

Using the first method, a set of reasonable and plausible assumptions have to be defined in order to observe consequences after a model run in the second, a desired goal has to be defined and one has to find the conditions to achieve that goal. The first way consists of a straight-forward computation, the second implies an interactive approach in which normally certain constraints have to be observed, often caused by large scale global linkages.

Both ways allow the investigation of alternative energy scenarios for the future so that the energy system in its complex structure becomes transparent with respect to simulated external events and/or interferences caused by defined energy policy targets. Even the next decision to be taken can be evaluated in its future consequences and a minimum number of necessary actions and decisions which will fit into a flexible energy future can be outlined. What is practicable and what is controllable can be made apparent and an incentive is given to necessary structural changes and innovations. Fig. 4 makes this procedure evident. Within a spectrum of lines of reasonable developments of the energy system under various conditions and assumptions - economical, technological, environmental - it is possible to define a set of decision steps which have to be taken to keep open as many options as possible, especially with regard to the long term security of energy supply and economic welfare. This set of decisions can be seen as located within the circular area of Fig. 4 and represents the minimum of decisions to be taken which will fit into each decision chain symbolised by the branching paths defining alternative paths of development of the energy system.

In contrast to traditional outcomes of energy economic planning which usually provide, as a decision aid for future planning, a so-called energy prognosis and which consists of relatively clear statements presenting a future pattern of development, this new way of producing decision aids for energy planning does not rely exclusively on one future development line, but takes into consideration the possibility and probability of alternative developments. In this way, a fixed decision sequence which will preclude a secure energy supply for different courses of events can be avoided. The certainty that at least a minimum of decisions which have to be taken are reliable and "hard" will reduce some of the uncertainties which are always inherent in the planning of the future.

4. SOME RESULTS

The model system has recently been operated in the ways mentioned above making possible the elaboration of future, feasible energy paths for the Federal Republic of Germany. The conditions for realization of these paths revealed for the national energy policy some important facts which up to now had not been recognized. Policies for conservation of energy and the necessary development and market penetration of new technologies could be formulated. Besides the projections of future requirements of energy in the various sectors of the whole economy, it was possible to identify priorities for R&D, in particular, by making apparent "hard" decisions - in the sense described above - which have to be taken. In the following, a summary outline of the main results [5] is given.

- The total economic growth in Germany is and will remain - at least in the short and medium term - the main determinant of energy consumption. Since the current dominant political goals assume a desire to solve problems of unemployment and other social and political problems by means of economic growth, a further increase in energy demand is to be expected. The present "glut" in the energy is an effect of the present economic situation and therefore should not lead to any wrong conclusions regarding long-term developments.

- The future increase in energy demand depends not only on economic development but also on the patterns of consumption in energy demand and supply.

Fig. 5 shows the expected development in primary energy consumption under the assumption of medium economic growth - defined as 3-2-1 case, that means an average growth of 3% per year from 1975 to 1985, 2% per year from 1985 to 2000 and 1% per year from 2000 to 2010 - and extrapolation of the historical structures of energy demand and supply.

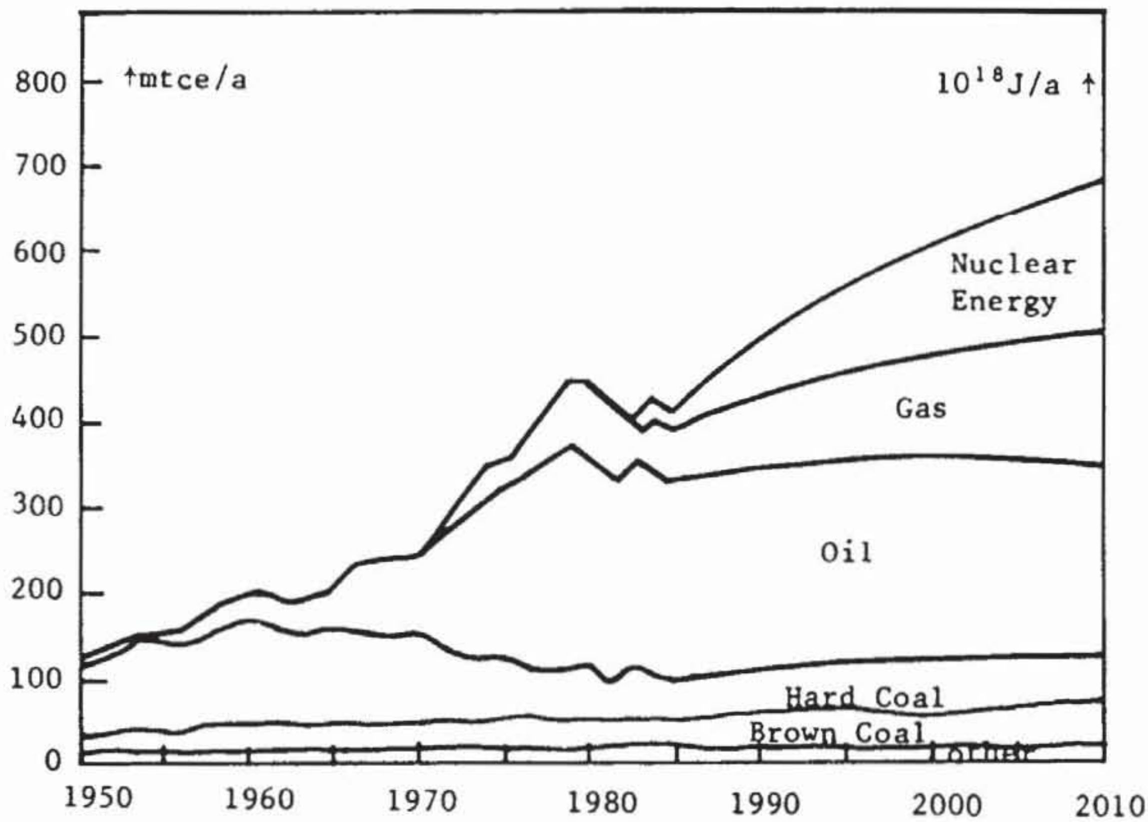

FIGURE 5 - Development of the primary energy consumption (Trends on continued scenario: 3-2-1 case)

Under these assumptions, the results indicate an energy demand which in 2000 is about 60% and in 2010 about 75% more than that of today.

- The primary energy demand structure is impossible to realize, because of the bounds for the possible availability of individual energy carriers, as seen in Table 1. That is very much the case for mineral oil as Fig. 6 shows. The lower curve of mineral oil imports up to 2010 would correspond to the development of primary energy consumption under medium economic growth shown in Fig. 5.

TABLE 1 - Possible bounds to future energy availability in the Federal Republic of Germany (10^6 tce/a)*

Energy carriers or sources	Of which	Year 1976	Year 2000	Up to the year 2010
Hard coal	Domestic production	89.6	< 100	→
	Net import	- 12.4	< 40	→
Brown coal	Domestic production	36.3	< 45	→
	Net import	1.2	-	–
Mineral oil	Domestic production	8	-	–
	Net import	194.9	< 200	↓
Natural gas	Domestic production	20.1	< 15	↓
	Net import	31.0	< 100	↘
Uranium/Thorium	Net import	7.9	< 250	→
Renewable energy sources (incl. heat pumps)	Indigenous	-	< 50	↑

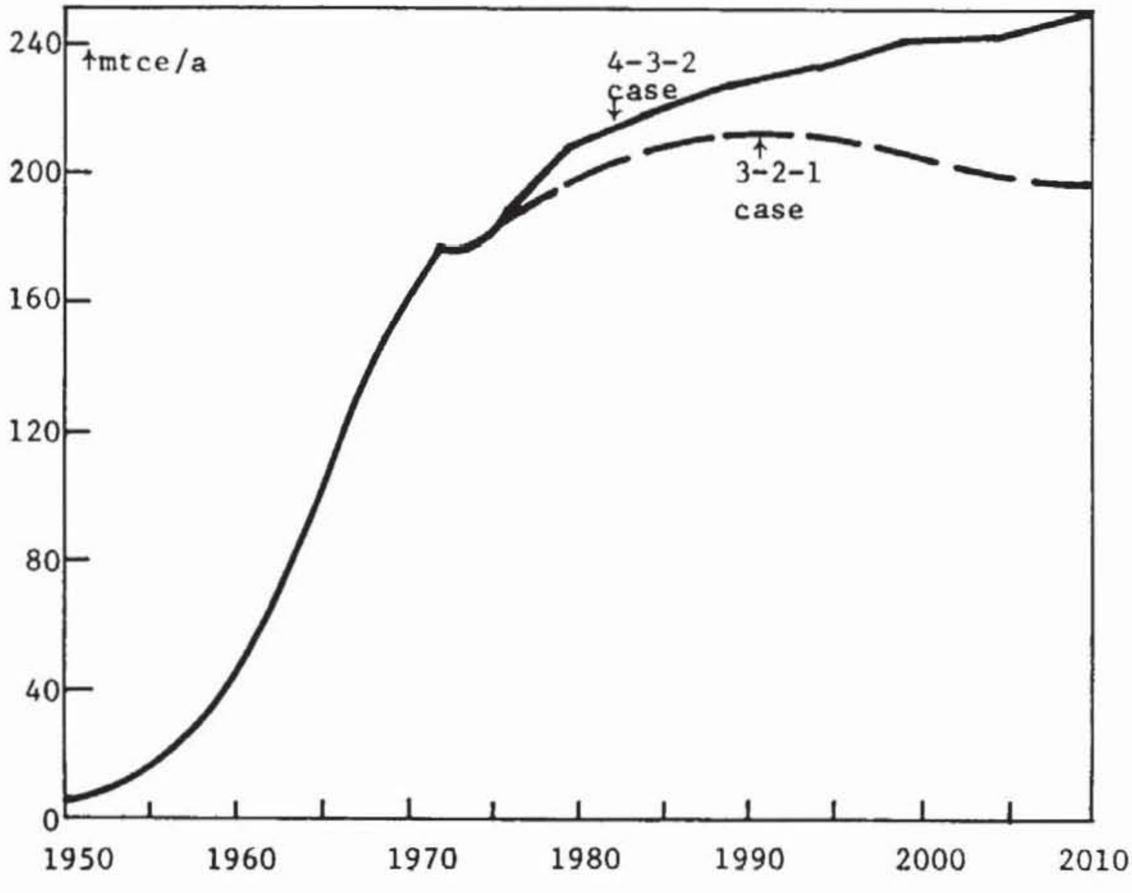

FIGURE 6 - Development of the net mineral oil import

*Tons coal equivalent / annum

- Higher economic growth rates, meaning one more percentage point per year (defined as 4-3-2 case), would make this situation even more serious as the upper curve in Fig. 6 shows.

- To minimize such a risk, immediate action must be taken. Otherwise the race against time could be lost to the disadvantage of the economy as a whole.

- The measures to be taken should be limited to single sectors. Thus neither energy conservation nor coal can solve the problem alone. A long term set of planned measures is therefore required which will combine to ensure a secure "energy future".

- To keep open the option for a politically and energetically secure rate of economic growth in the long-term, the following particular steps, e.g. "hard" decisions, must be taken:

  i. Energy saving must be supported and carried out with more urgency if an effective contribution is to be expected. This effort must extend to all sectors of the economy. These last statements should become clear as the results of calculations are presented shortly, which were based on the assumptions shown in Fig. 7.

  In the residential and commercial sector, all buildings should be fitted with better insulation by the year 2010, such that in 2010 50% of all buildings for human habitation would be equipped with improved means of heat insulations. Solar collectors and heat pumps would be implemented to the lower levels but only in suitable buildings, mainly detached and semi-detached houses.

  It was further assumed that in the industrial and transport sectors energy savings are made which are shown in Fig. 8.

  In Fig. 8 we see the assumed development of the conservation factor in industry (separately for fuel and electricity), and in the transport sector. The values are based on an estimate of realizable and mutually supporting measures.

  Based on such a list of desired measures which, although of considerable scope, are still realizable, the following results were attained in the various

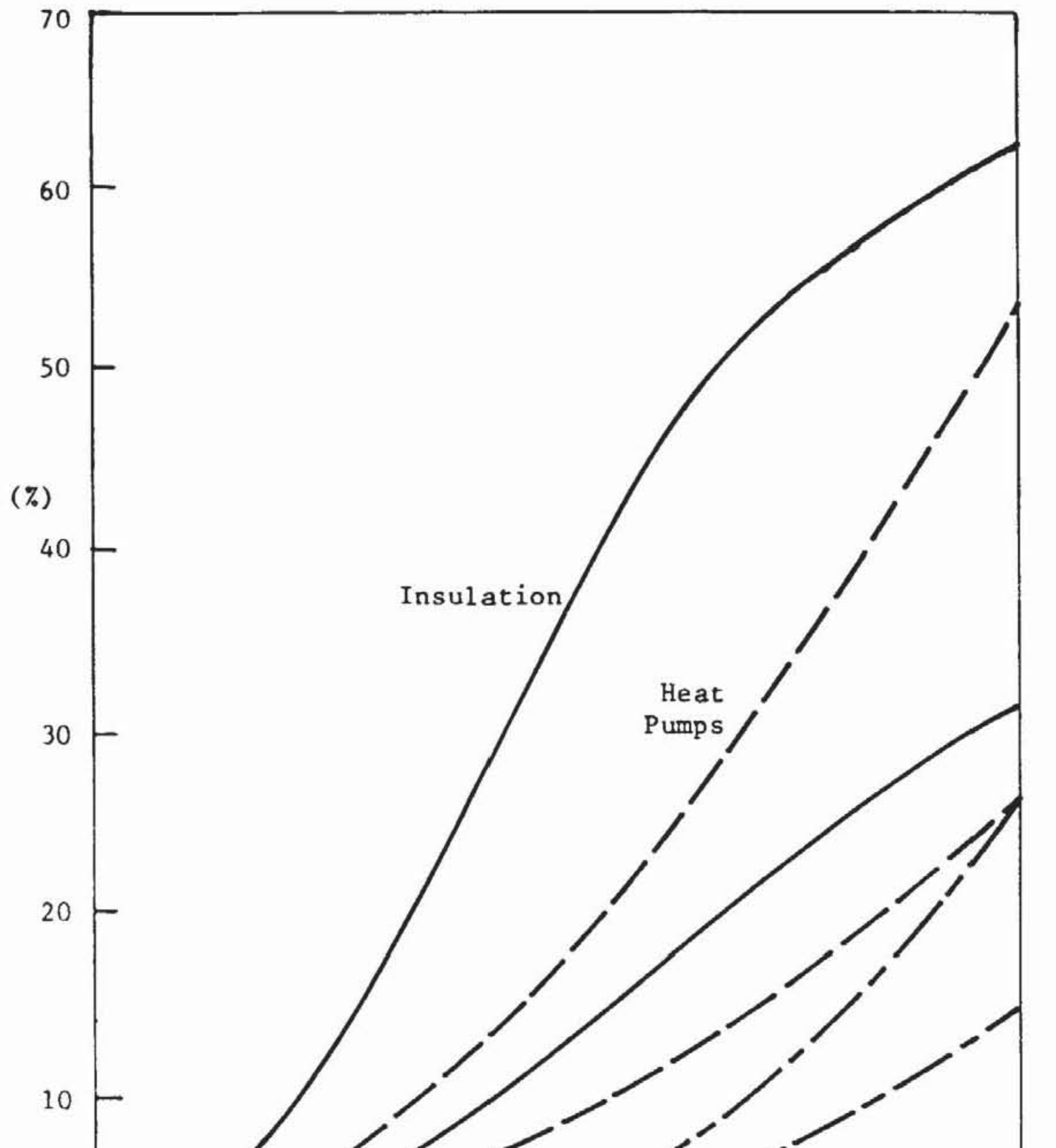

FIGURE 7 - Upper and lower levels of application of alternative measures of energy conservation

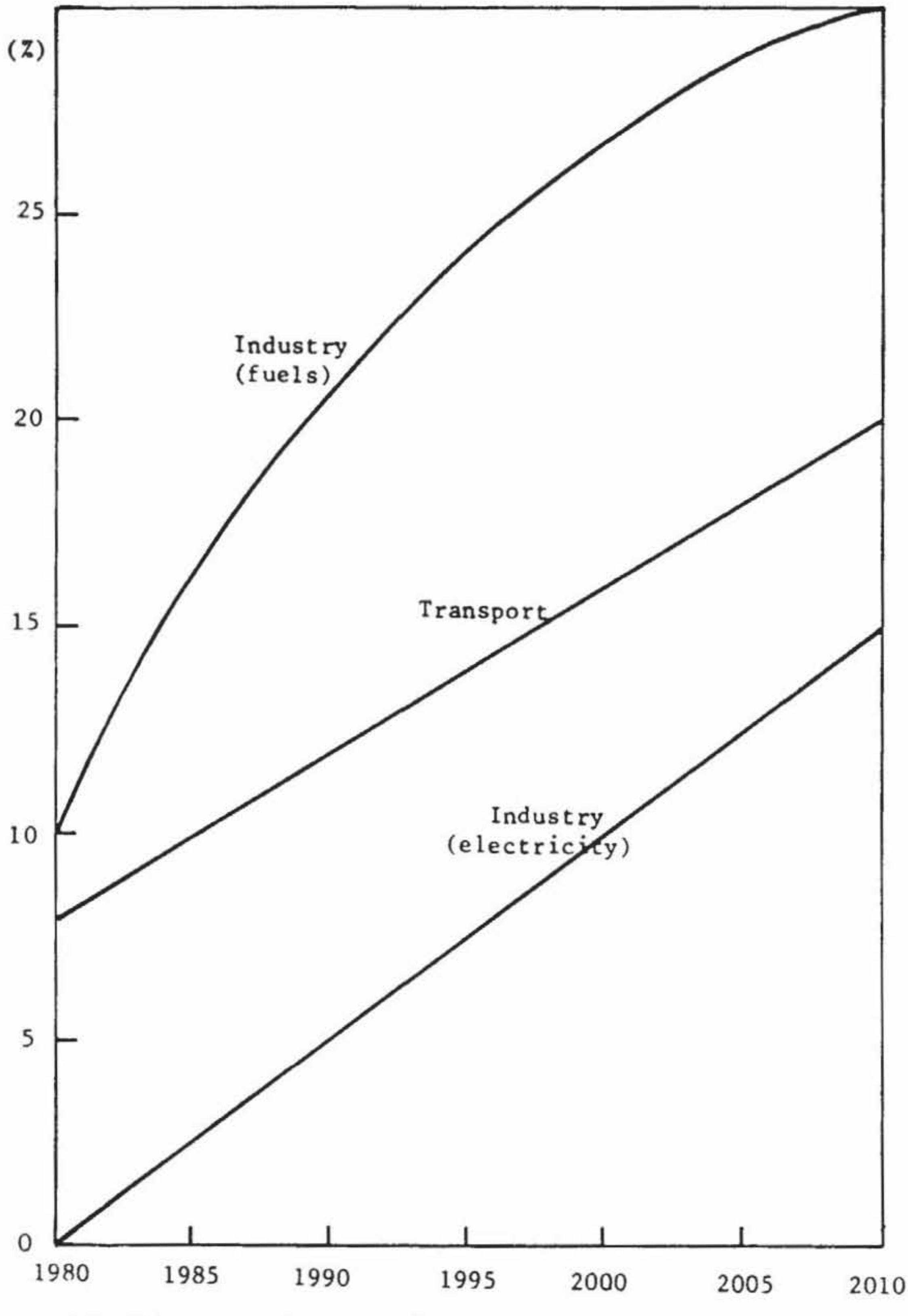

FIGURE 8 - Development in the conservation factors in industry and transport

branches of the economy and society (See Table 2). Considering only private households, 2% energy savings in end energy or 1.5% in primary energy could be achieved. This is due to the fact that in the historical trend case (Fig.5) energy conservation measures due to present regulations are already taken into account. If we include commercial users, which is the sector which provides services, 6.5% end energy or 6% primary energy savings would be possible. However, the figures 20% and 16% for the case of a comprehensive energy saving strategy in private households, commercial users, industry, and transport, make it clear that all sectors of the economy and society must be involved in order to make a significant total contribution to energy saving. Nevertheless it is obvious that this contribution is not sufficient in the context of secure energy planning if we consider that an underestimate in the long term economic growth of just one percent (compared to medium growth) would be enough for the effect of the energy savings achieved to be cancelled out.

TABLE 2 - Possible energy savings with alternative conservation measures in the year 2000.

Sectors included	Energy saving End energy (%)	Energy saving Primary energy (%)
Private households	2.0	1.5
Private households and Commercial users	6.5	6.0
All sectors of the Economy	20	16

TABLE 3 - Development of the primary energy consumption in the 3-2-1 case (4-3-2 case)

PRIMARY ENERGY (10^6 tce)							
Time	Hard coal	Brown coal	Mineral oil	Gas	Nuclear energy	Hydro and other	Consumption Σ
1985	81 (85)	40 (40)	210 (225)	83 (87)	30 (42)	10 (11)	454 (490)
1990	88 (92)	41 (41)	215 (233)	97 (105)	56 (75)	12 (12)	509 (558)
2000	92 (101)	42 (42)	208 (241)	118 (138)	109 (160)	14 (15)	583 (698)
2010	96 (110)	42 (43)	204 (245)	125 (152)	165 (248)	15 (18)	647 (816)

In Table 3 once again are the results for primary energy consumption in those scenarios which in a sense are an extrapolation of historical trends and which differ in their economic growth rate by 1%. We see that for the year 2000 the primary energy consumption turned out to be 583 and 698 mtce. 16% savings as compared with now would almost exactly correspond to this difference.

- Further steps, e.g. "hard" decisions, to maintain a politically and energetically secure long term rate of economic growth can be formulated as follows:

ii. The present production capacity for coal must be maintained at all costs because large quantities of coal must be available in the long term.

iii. A long term build-up of coal fired power stations should only be allowed if substitution of nuclear electricity is necessary. Otherwise coal should be used for conversion to other products to be able to solve the problems in the oil and gas market. So it seems necessary around the end of the 1980's not to undertake a further construction of coal for other purposes than electricity production.

In a programme of coal gasification and liquefaction plant construction, care should be taken that the coal power stations still in operation are supplied with fuel for the remainder of their lifetimes from the available coal. This point is illustrated for the case of brown coal in Fig. 9. A halt to the building of brown coal power stations from 1988 would mean that the fuel use in the remaining power stations would have to fall off according to the curves shown. An agreed programme of allothermal (nuclear) or autothermal brown coal gasification plant construction takes account of this, as Fig. 9 shows. This means that the building of brown coal gasification plants is such that the difference between the available brown coal, represented by the curve for the trends continued scenario, and the coal used in power stations remaining after the halt in construction, can be taken for gasification.

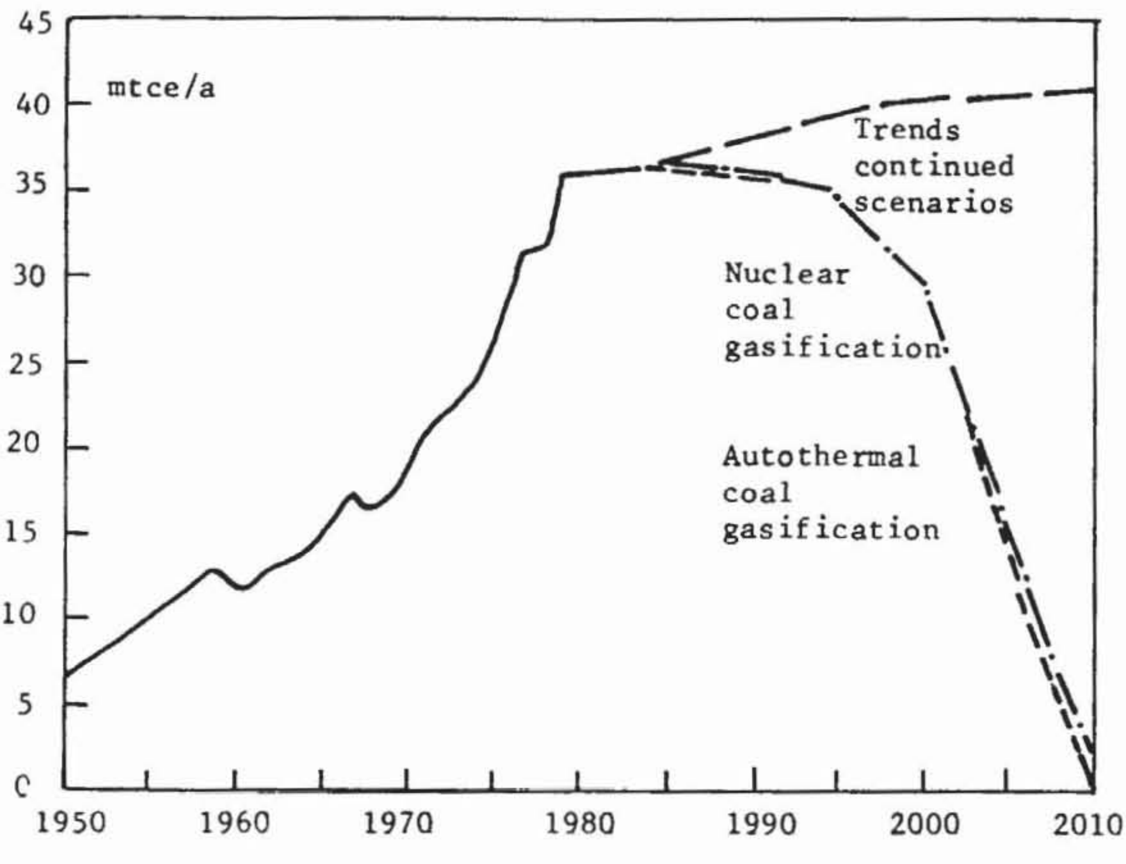

FIGURE 9 - Brown coal input into power stations

iv. Nuclear power must have a firm place in the energy supply of Germany, both for electricity production, and for supplying process heat. Without nuclear energy, economic growth could be reduced even in the medium term. In Fig. 10, we see the possible economic development based on the energy availability in the case of a limited amount of 30 GW nuclear from the year 1992. A strong deceleration of economic growth could be the consequence. One might even expect negative growth rates in the long term, in spite of the fact that accelerated energy conservation measures and processes to substitute for nuclear electricity were simulated in the calculation.

v. Finally:
The steps referred to should be further supported by other measures which permanently displace mineral oil from the end energy sector. Stronger implemention of electricity and district heat is one possibility, but also the products of coal conversion such as gas, methanol and heat are suitable substitutes.

By simulating this set of measures, a path of development for the energy economy could be worked out which may be seen as realizable. Fig. 11 shows the corresponding primary energy consumption.

5. SIMULATION MODELS: VALIDATION AND LIMITATIONS

Finally, it seems necessary to make some remarks regarding the validation of simulation models, and the frontiers of model application.

Regarding the structure of a model, the question immediately arises whether or not the model is a reliable representation of the real world system in its behaviour. This problem of model validation is an important task within model development. There is no doubt that a procedure to obtain a complete validation does not exist. But there are possibilities to analyse at least partially the validity of a model by use of special tests based on plausibility considerations. Reasonable test procedures are as follows:

- The rational and logical inquiry into the model structure with respect to relevant influence factors and reasonable relations between variables.

- The reproduction of system behaviour in the past. A positive outcome of this test, however, does not prove the reliability of the model. Moreover, this test requires a great amount of time and data.

- Investigation of the model behaviour in exceptional or extreme environments. Incorrect model relationships may lead in such cases to illogical and unexplainable results.

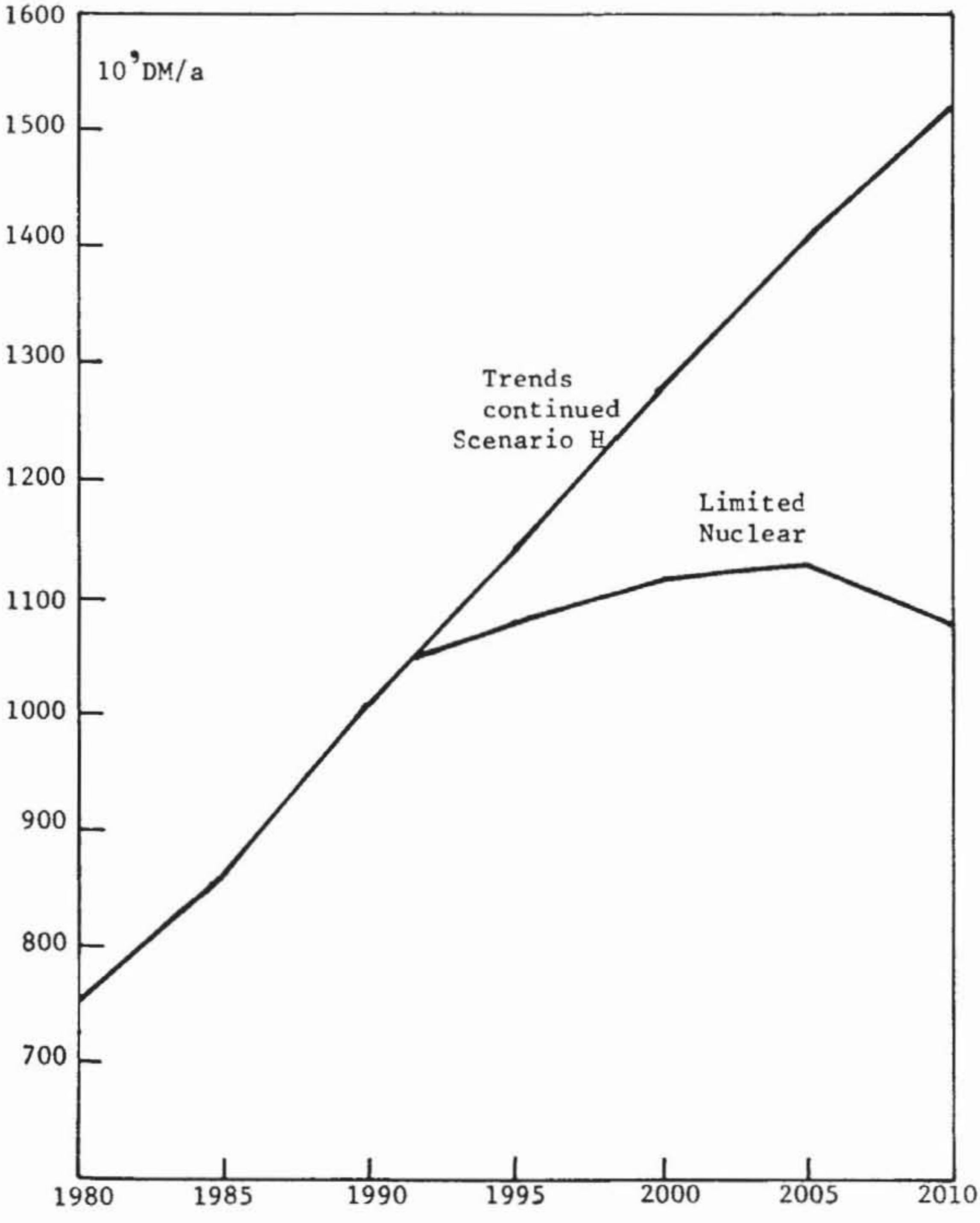

FIGURE 10 - Development of the gross national product

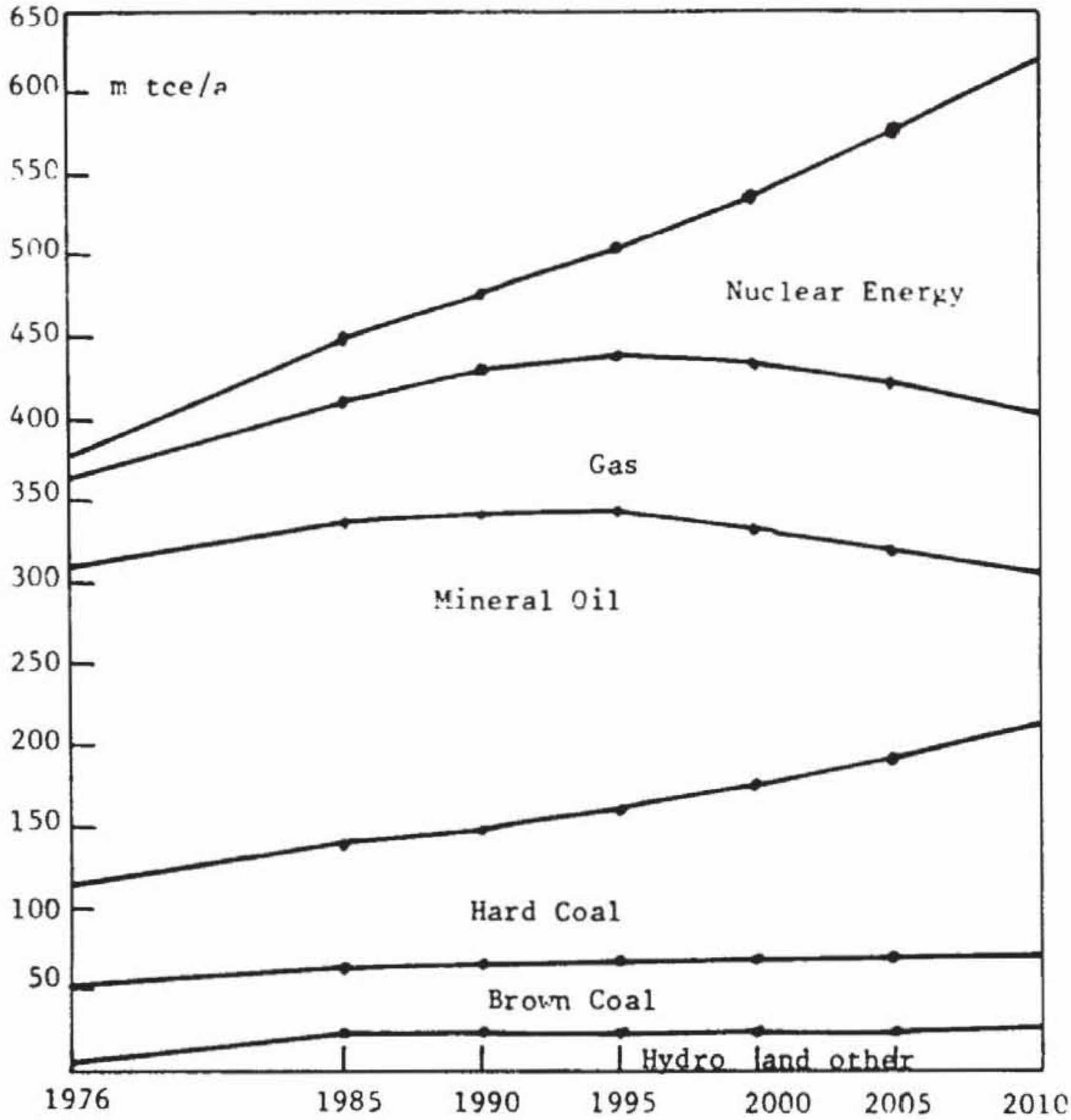

FIGURE 11 - Development of primary energy consumption

Despite these limitations, at least a partial validation is a necessary and essential part of any model development task.

Energy models offer energy decision makers a promising means to achieve a better understanding of the problems and choices before them. To develop the potential of this decision aid and to take advantage of it, it is extremely important to be aware of its limitations. It is true that a mathematical model:

- forces a precise statement of the problem and objectives and requires an in-depth study of the system being described, as a rule resulting in a better understanding of the system,

- offers a framework within which experiments can be conducted and the consequences of alternative decisions and actions can be analyzed, and

- is able to handle a mass of data.

But it should be kept in mind that a model is not reality; it is always only a simplification of the real system it represents.

REFERENCES

1. J.M. Beaujean and J.P. Charpentier,"A Review of Energy Models No.4", July 1978, RR-78-12, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

2. St. Rath-Nagel, "Alternative Entwicklungsmöglichkeiten der Energiewirtschaft in der Bundesrepublik Deutschland", ISR 28, Birkhauser Verlag, Basel und Stuttgart, 1977.

3. A. Voss, "Ansatze zur Gesamtanalyse des Systems Mensch-Energie-Umwelt", ISR 30, Birkhauser Verlag, Basel und Stuttgart, 1977.

4. A. Voss, et.al., "Dynamische Energiemodelle als Planungs - und Entscheidungshilfe dargestellt an einem Energiemodell für die Bundesrepublik Deutschland", in: Energiemodelle für die BRD, Ed. by Ch. König, ISR 42, Birkhauser Verlag, Basel und Stuttgart, 1977.

5. K. Schmitz, "Langfristplanung in der Energiewirtschaft", ISR 65, Birkhauser Verlag, Basel und Stuttgart, 1979.

6. K. Schimtz, H.P. Schwefel, "Finding Reasonable Energy Policies by Means of a Dynamic Simulation Model", in Proceedings of the International Symposium Simulation '77, ACTA Press, Zürich, 1977.

7. U. Schöler, et.al., "A Dynamic Energy Model for the Countries of the European Communities", EUR 5953, Commission of the European Communities, Brussels, Luxenbourgh, 1978.

8. F. Drepper, "A Data-Model Interface for Modular Dynamic Simulation", Winter Simulation Conference, Miami Beach, Florida, 1978.

9. H.P. Schwefel, R. Heckler, "Superposing Direct Search Methods for Parameter Optimization onto Dynamic Simulation Models", Winter Simulation Conference, Miami Beach, Florida, 1978.

DISCUSSION

Voss was questioned on his assumption of fixed market shares for the different supply technologies in the simulation model. He replied that although the market shares were fixed for a given simulation, they were obtained from an optimization model and manually transferred to the simulation model, so that in effect an iteration process was occurring.

Several participants raised points on the feedback between the energy supply model and the national economic model. If consumers' energy bills were reduced through greater energy conservation they would have more money to spend on other goods, how was their increased spending power accounted for in the model? Voss replied that increased demand for better insulation etc. was taken care of in the model via the input-output matrix, which was exogeneous and static. There did not, however, appear to be a consumption function which accounted for the secondary effects eluded to in the question. Voss was asked if they had computed the price elasticity implicit in the model. This had not been done.

Another question centred on how increased investments and labour requirements in the energy supply sector affected the rest of the economy. Voss replied that if more labour were required in the energy sector, less would be available to other production activities. In the case of investments, increased demand for investment goods from the energy sector would cause other sectors of the economy to produce more to meet this demand. The input-output matrix provided the check on consistency. There was, no capital constraint, but a capital feed-back in the model. Neither was there any feed-back to wage-rates of rate of interest as a result of increasing scarcity.

Voss was asked about his criteria for model validation. These were not statistical, he replied, but were based on subjective judgement of goodness of fit for the past 15 years of data. Much of the work that had been put into the model (about 80%) had gone into validation. There, the main problem was sudden changes and fluctuations in the past.

In response to other questions, Voss explained that methanol was produced from coal; the environmental module was simply a pollution model; and that no depreciation of the capital stock was included.