ENERGY MODELS AND ENERGY POLICY PROBLEMS

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1. INTRODUCTION

I have been involved in energy modelling for planning and policy making for more than ten years now and I am still convinced that systematic and careful modelling can contribute to better decisions in the energy policy area. I think I should make this statement right at the beginning, because my contribution will be somewhat critical. It will to some extend focus on the failures, misuses and unresolved issues in energy policy modelling rather than report about the successes, which although they are there, are still small compared with the potential benefits and prospects, that energy models can offer to the decision makers. Nevertheless I will start with a brief review of the history and methods used in energy modelling and I will describe a limited number of representative models in order to illustrate the present state of the art. The review is not intended to be exhaustive or to provide a comparative evaluation of models designed for similar purposes. Rather, the models are reviewed to illustrate the advances and the structure of recent and current efforts by energy modellers.

Thereafter I will discuss the question whether or not energy models have successfully contributed to help solving the complex problems facing the energy planner and energy policy maker. I hope to make clear, that despite the tremendous progress made in the design of complex, large-scale models, energy models were by far not as successful as they could have been in their contribution to the decision making process. And I will argue, that a new more realistic attitude, a new orientation of the preferences of the model builder is needed, that expectations must be redirected to what is needed and can be achieved, rather than to promote and construct more sophisticated or even universal models.

2. ENERGY MODEL DEVELOPMENT

The sharp increase in the price of energy in the early seventies have confronted many nations, particularly energy importers with unprecedented economic challenges they were ill-prepared for. The economies of the less affluent oil importers in the developing world were severly distorted. Even among the affluent industrialized countries, the cost of adjustment to higher energy prices in terms of higher overall price levels, unemployment, industrial restructuring, adverse distributional effects and environmental quality, have been pervasive.

Although efforts to develop energy models began in the early sixties, that is well before the first oil crisis in 1973, it was the growing awareness of the energy problem originating from this event that forced an explosion in the development of energy models. Exact figures concerning the energy models developed so far are not available, but in the reviews of energy models published by the International Institute for Applied Systems Analysis (IIASA) /1, 2, 3/ up until 1976 alone some 144 different models were characterized and classified. The individual models vary greatly in their objectives, they address a broad scope of problems for geographical areas of widely different sizes and they employ a variety of methods originating from several scientific disciplines.

The energy models developed in the sixties focused mainly upon the supply and demand of a single energy form or fuel like electricity, oil or natural gas. Faced with the complex problem of optimal allocation and routing of crude oil and oil products between different oil sources, refineries and demand centers, the petróleum companies have developed and applied particularly large allocation models, as well as models for the refining process. Another example of a successful application of models of the sectoral type are the models used for the analysis of electric utility operations and expansion plans. A large number of models have been developed and are used to evaluate the optimal expansion strategy of the power plant system required to satisfy an increased electricity demand. The models determine the optimal mix and timing of new power plants of different types so that the electricity demand over the planning horizon is satisfied at minimum discounted overall cost, including capital, fuel, as well as operating costs.

Both kind of models mentioned above focus on the supply side, that is, on the best way to satisfy an assumed energy demand. Energy is an exogenous input to these models and is often provided by econometric demand models, estimating energy or fuel demand as a function of energy prices and other determinants such as population, economic growth, etc..

A major criticism concerning sectoral, single fuel or energy form models is that they treat the development of the sector or fuel in question as isolated from the rest of the overall energy and economic system, thereby ignoring that there are many different ways to satisfy given energy service demands such as space heat, industrial process heat and transportation. A sectoral, single fuel model cannot adequately describe the interfuel substitution related to changing energy prices, technological development or environmental considerations in the different sectors of energy use.

Complying with these requirements was the main reason for the development of energy system models, describing the energy flows from different primary energy sources through various conversion and utilization processes to different end use demands. It was at the beginning of the seventies, when the work on energy system models began.

A national energy balance as shown in Fig. 1 can be viewed as a simple static model of the energy system, because it accounts at a single point in time for all energy flows from the primary energy sources, through conversion processes, to the ultimate use of various fuels and energy forms.

Most of the energy system models are based on the network representation of the energy balance approach, as it is shown in Fig. 1. Using this network of flow of resources like coal, oil, gas, nuclear or solar to various demand sectors like industry, transportation, households and the commercial sector as a simple accounting framework, the consequences of alternative ways to satisfy an estimated demand development in each of the major end-use sectors can be simulated and evaluated in terms of primary energy consumption, required conversion capacity etc.. Extensions of this type of model to analyse the impact of alternative energy supply strategies on the environment and in

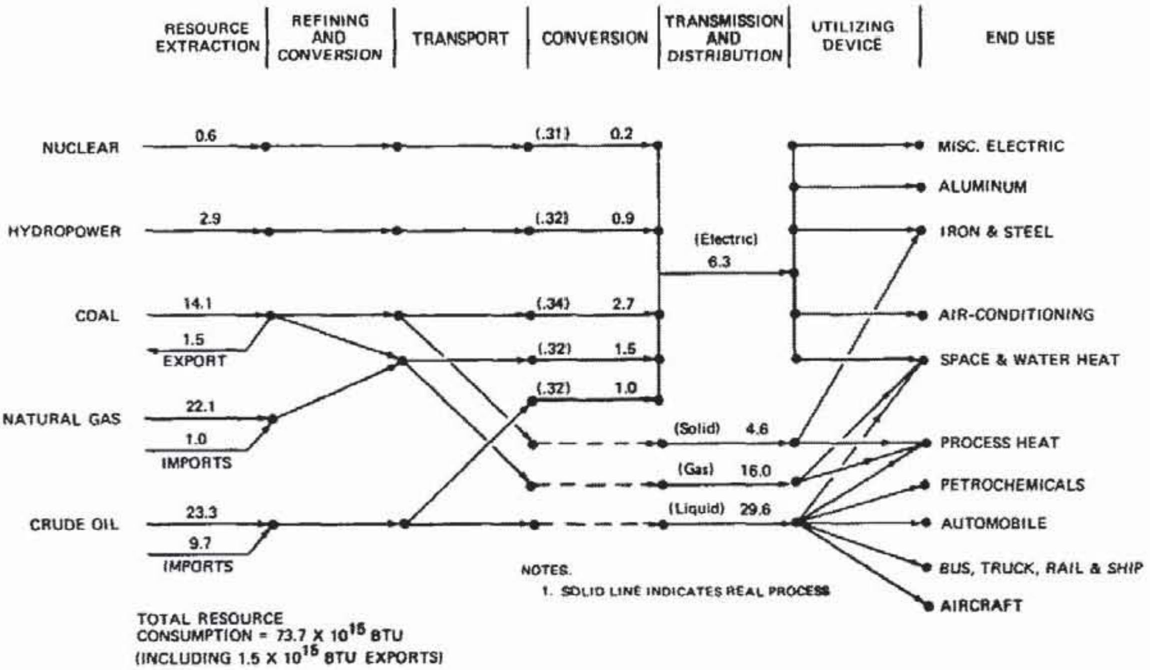


Fig. 1: National Energy Balance

terms of energy cost are easily attainable and have been used in the past. Besides these network accounting models, a series of optimizing models of whole energy systems were developed from the beginning of the seventies. These models were designed to determine the optimal allocation of energy resources and conversion technologies to end-uses using the network representation of the energy system. The models are either static with the optimization process seeking a minimization of cost for a single target year, or they are quasi dynamic and attempt to minimize the present values of costs over the whole planning horizon, subject to the demand and to a set of constraints reflecting resource availabilities and/or environmental considerations.

Accounting and optimization models of this type focus on the technical structure of the energy systems. Energy demand is usually an exogenous input to them. Therefore these models do not allow for demand adjustments due to higher energy prices or to changed GNP growth caused by rising energy cost and limited energy supplies.

Handling these issues requires models linking the energy sector with the rest of the economy. Various approaches to link economic models to models of energy demand and supply have been investigated. Generally speaking two classes of energy-economy models can be distinguished. Integrated models which explicitly describe the interrelations between the energy sector and the economy and model sets which consist of an economy and an energy system model which are linked by the transfer of data via a human interface.

This short glance back into history should show that, although the construction of energy models began only 20 years ago, there have been several important development phases as single fuel or sectoral models evolved towards models of complete energy systems and energy economy models.

This historical development pattern seems to be also a useful scheme for the classification of energy models. In the following I will distinguish between

- Single Fuel Models
- Energy System Models and
- Energy-Economy Models.

Later I will describe in some more detail typical approaches used in modelling the entire energy system and the energy-economy interactions.

But let me first comment on the methods used in energy modelling. As it was not the main goal of the energy model builders to develop new and better methods, they most often referred to the corresponding improvements and developments of other fields of science e.g. econometrics, statistics, operations research, computer science, and system science. Looking back, one can say that there are three modelling methodologies that have been applied predominantly in energy models, namely engineering process analysis, mathematical programming, and econometrics.

Econometric methods are found most often in representations of the energy demand side emphasizing the behavioral aspects of decisions on the sides of both the consumer and the supplier. Statistical techniques are used to estimate the structural parameters of the behavioral equations, e.g. macroeconomic production functions or price elasticities from observed data. Econometric models are, in general, of a higher aggregation level than process models, which often cover quite a lot of technical details of the energy supply system. This is independent of whether it is conceived as a simple accounting or as an optimization model. The linear programming technique has been used far more than other mathematical programming methods, because of its capability to solve large problems.

In addition to these methods, energy models, which make use of the input-output method, the system dynamics approach or the method of game theory were occasionally developed.

3. THE STATE-OF-THE-ART IN ENERGY MODELLING

Following the classification of energy models mentioned above, I would now like to illustrate the state of the art in energy system- and energy-economy modelling by describing typical representatives of these classes of energy models in some more detail.

	METHODOLOGY	
MODEL	SUPPLY SIDE	DEMAND SIDE
BESOM (BROOKHAVEN)	LINEAR OPTIMIZATION (STATIC)	EXOGENOUS
EFOM (GRENOBLE)	LINEAR OPTIMIZATION (QUASI DYNAMIC)	EXOGENOUS
MESSAGE (IIASA)	LINEAR OPTIMIZATION (QUASI DYNAMIC)	PARTIAL EXOGENOUS (PRICE DEPENDENT)
MARKAL (JÜLICH)	LINEAR OPTIMIZATION (QUASI DYNAMIC)	PARTIAL EXOGENOUS (PRICE DEPENDENT)

Fig. 2: Energy System Models

Fig. 2 lists several of the well-known energy system models together with the methodology used. All of these modesl use the linear programming approach. They focus on the technical, economic and environmental characteristics of the energy conversion, delivery and utilization processes that comprise the total energy system. While BESOM provides a "snapshot" of the energy system configuration, the other models are designed to analyze the evolution of the energy system ove a time period.

Let me now briefly describe the MARKAL model as a typical representative of the energy system models /4/. MARKAL was specifically designed to follow the evolution in time of the introduction of new technologies and the corresponding decline in the use of hydrocarbon resources, especially imported petroleum. Using the model, it is possible to assess the relative attractiveness of existing and new technologies and energy resources on the supply side of the system and, on the demand side, the long-range effect of conservation, of efficiency improvements in end-use devices and of inter-fuel substitution.

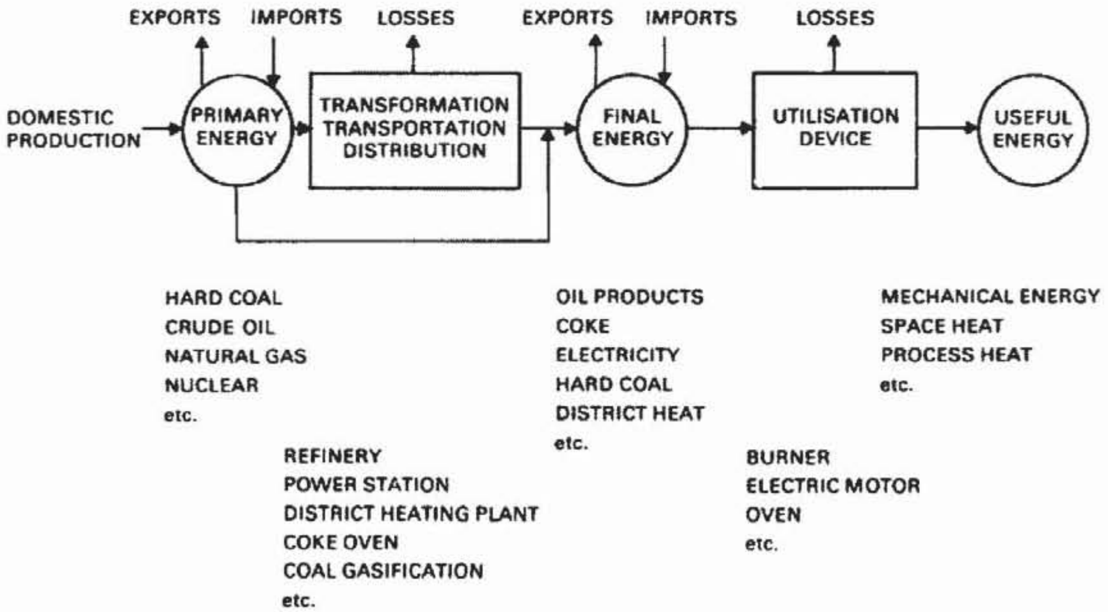


Fig. 3: The MARKAL Model

Fig. 3 shows the principal energy flows represented in MARKAL. Three types of energy are distinguished. Primary energy (e. g. domestic coal, imported crude oil) is transformed into final energy (e.g. electricity, refined oil products, district heat) through transformation and conversion, transportation and distribution processes. The final energy is then consumed in end-use devices to produce useful energy (e.g. space heat, mechanical energy) to satisfy the energy service demand, for example the demand for a warm room or the travelling from Stuttgart to Copenhagen. Useful energy or energy service demand are the exogenously specified driving variables in the MARKAL model.

MARKAL is a multiperiod linear programming model with explicit representation of some 200 technologies for energy production, conversion and end-use. The general model structure is illustrated in Fig. 4. The objective function is the sum of discounted costs of fuels, operating and maintenance, transportation and investments for adding new capacities, to satisfy the energy demand over the planning horizon. The objective function is to be minimized under a set of constraints. The constraints involve balances for individual fuels as well as limits on the installation and operation of technologies. The capacities of the

<u>OBJECTIVE FUNCTION</u>

MINIMIZE $\sum_{T}^{T} \beta^{T}$ [PRIMARY FUEL COSTS + OPERATING A. MAINTENANCE COSTS + TRANSPORTATION COSTS + INVESTMENT COSTS OF ADDING NEW CAPACITIES]

OVER THE TIME HORIZON T, SUBJECT TO:

- DEMAND CONSTRAINTS
- SUPPLY CONSTRAINTS
- CAPACITY CONSTRAINTS
- RESOURCE CONSTRAINTS
- IMPLEMENTATION CONSTRAINTS
- ENVIRONMENTAL CONSTRAINTS

Fig. 4: General Model Structure of MARKAL

different energy technologies depend on investments made in earlier periods and the defined lifetimes of existing technologies. Because of this representation, the model is able to describe the phasingout of existing plants and the build-up of new capacity properly. Another dynamic constraint utilized in the model limits the cumulative amount of particular resources available over the entire time horizon. The electricity and heat generating technologies have been modeled in MARKAL with explicit treatment of the load structure related to the diurnal and/or seasonal variations of the demand. Environmental considerations can also be taken into account.

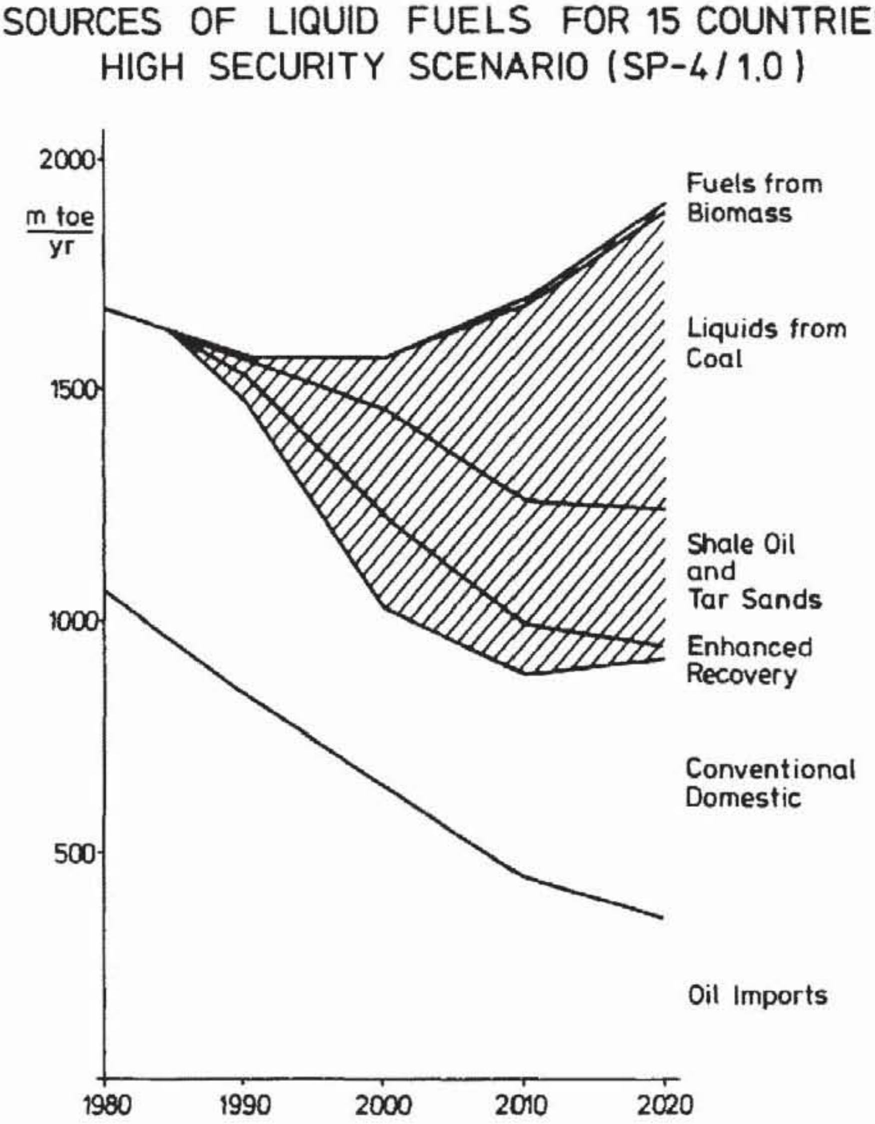

SOURCES OF LIQUID FUELS FOR 15 COUNTRIES:
HIGH SECURITY SCENARIO (SP-4/1.0)

Fig. 5: Typical MARKAL output

Fig. 5 shows a typical result obtained from MARKAL indicating how the substitution of oil imports by new liquid fuels producing technologies takes place under a certain price escalation of crude oil /5/.

Another set of interesting information, which these models provide, is the trade-off between energy system costs and oil imports, as displayed in Fig. 6. The curve shows what a replacement of oil imports would cost the economy, which would have the invest in new technologies or push conservation. In the figure 6, PS-1 denotes the optimum allocation of fuels and technologies for a least cost scenario. If we move towards the left, the system costs increase while oil imports decline. The fact that a premium is to be paid for lower oil import energy systems is denoted by scenarios SP-1/PREM-1 and SP-1/PREM-2. Three different patterns are shown (Spain, United States, United Kingdom) illustrating differences among countries /5/.

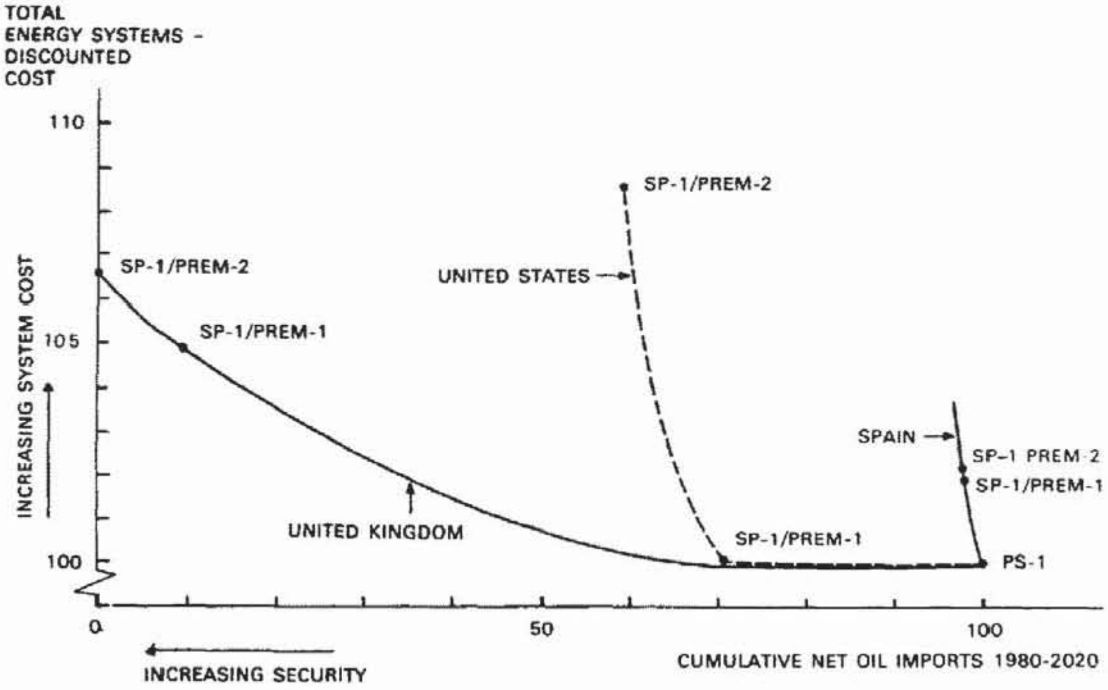


Fig. 6: Trade Off between Energy System Costs and Oil Imports

Each point of this trade-off curve represents a scenario, which itself yields a different mix of technologies and a different temporal evolution of each technology. Other trade-off, e.g. between costs and environment can be examined in a similar approach.

It should be mentioned, that this kind of linear programming models of the energy system, are able to take price demand elasticities into account. In the model the response to energy price increases is determined in three forms: investments in conservation, investments in new technologies with higher efficiencies and adjusted useful energy demand levels. This feature is typical for a model type which is often called a partial equilibrium model, where energy demand itself is a variable depending on the price of energy /6/.

The second class of models I want to discuss in some more detail are the energy-economy models. Fig. 7 lists some of the well-known models, which explicitly take into account the linkages between the energy sector and the rest of the economy.

These integrated models share some common features. They all include a macroeconomic submodel, which represents to varying degrees, the production and consumption structure in the economy. They also contain an energy supply system with depiction of energy technologies, demand and prices. Finally, there are clear linkages between the energy sector and the rest of the economy.

A distinction is made between two categories of energy-economy-models. The first category consist of models which were basically designed to study the energy-economy interactions, while the second category contains models that were desinged by linking existing energy and economy models. Fig. 7 also indicates that optimization and econometrics are the methods most often used in energy-economy models.

ETA-MACRO is an example of the first category of energy-economy models /7/. As the name suggests, it consists of two parts: ETA is a process analysis model for energy technology assessment and MACRO is a macroeconomic growth model dealing with substitution between labor, capital and energy inputs.

MODEL	METHODOLOGY
INTEGRATED MODELS	
ETA-MACRO (STANFORD UNIV.)	NON-LINEAR OPTIMIZATION ECONOMETRIC
PILOT (STANFORD UNIV.)	LINEAR OPTIMIZATION
SRI (STANFORD RES. INST.)	ECONOMETRIC OPTIMIZATION
HUDSON-JORGENSON	ECONOMETRIC
ZENCAP (ZÜRICH)	ECONOMETRIC OPTIMIZATION
MODEL SETS	
IIASA (LAXENBURG)	LINEAR OPTIMIZATION, INPUT-OUTPUT, SIMULATION
CEC (BRÜSSEL)	LINEAR OPTIMIZATION, ECONOMETRIC, ACCOUNTING
DRI-BROOKHAVEN	LINEAR OPTIMIZATION ECONOMETRIC

Fig. 7: Energy-Economy Models

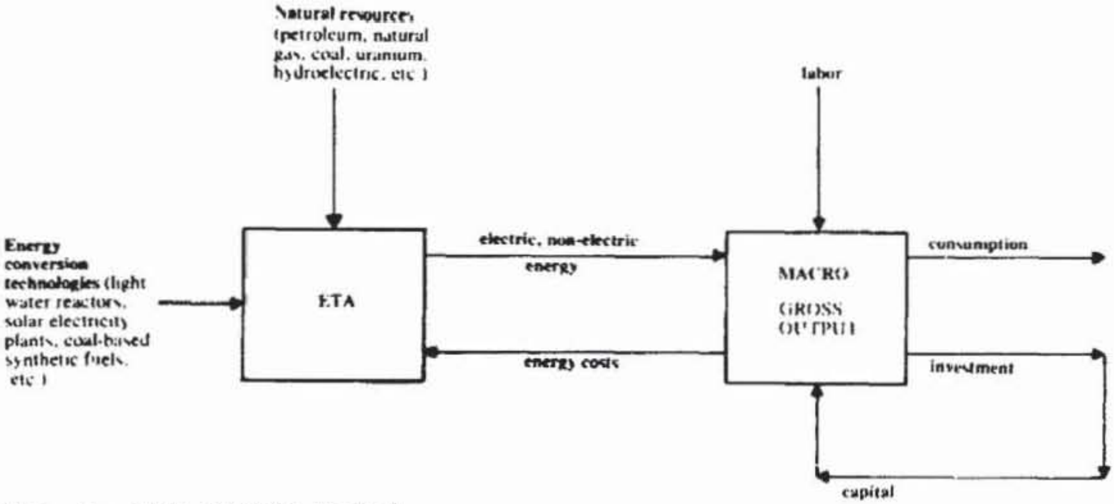


Fig. 8: ETA MACRO Model

Fig. 8 provides an overview of the principal static linkages between the energy and the macroeconomic submodels. Electric and nonelectric energy are supplied by the energy sector to the rest of the economy. Gross output depends upon the inputs of energy, labor and capital. The output is allocated between current consumption, investment in building up the stock of capital, and current payments of energy costs.

The entire model determines for each point in time an equilibrium between suply and demand, whereby substitution between labor, capital and energy inputs take place according to their availability and price. An increase in prices for energy will then affect the future level of energy demand, the fuel mix and the production structure of the economy in various ways. Price induced conservation and interfuel substitution will both have macroeconomic implications and the whole economy will adjust to the new equilibrium according to the time lags built into the model. This model is of the type which may be called a "general equilibrium model", in that it encompasses at the same time the effects, which the macroeconomy has on the energy system and vice versa the impacts of the energy system on the economy.

To be able to understand how the model works, it seems best to have a closer look to the MACRO submodel (see Fig. 9).

ALLOCATION OF ECONOMIC OUTPUT (Y)

$$Y = C + I + EC$$

LONG-RUN STATIC PRODUCTION FUNCTION

$$Y = \left[A(K^{\alpha} L^{1-\alpha})^{\rho} + B\,(E^{\beta} N^{1-\beta})^{\rho}\right]^{1/\rho}$$

WHERE $\rho = (\sigma - 1)/\sigma$ (FOR $\sigma \neq 0, 1, \infty$)

CAPITAL ACCUMULATION

$$K(T) = \lambda K(T-5) + 0.4 \cdot 5 \cdot I(T-5) + 0.6 \cdot 5 \cdot I(T)$$

$$(T = 5, \ldots, 75)$$

Fig. 9: Linkage between the Energy Sector and the Economy in the ETA-MACRO

As I mentioned already before, electric and non-electric energy are suplied by the energy sector to the rest of the economy. Like the material balance equations of an input-output model, aggregated economic output (Y) is allocated between interindustry payments for energy costs (EC) and "final demands" for current consumption (C) and investment (I) (First equation).

The production function employed assumes that the economy-wide gross output (Y) depends upon four inputs: K, L, E, N - respectively capital, labor, electric and non-electric energy. The elasticity of substitution among the input factors is separated in three fractions: substitution between capital and labor (denoted by α and $1-\alpha$), substitution between electric and non-electric energy (denoted by β and $1-\beta$), and substitution between capital/labor and electric/non-electric energy (denoted by ρ). If we were considering a static problem, the long-run production function would have the form of the second equation in Fig. 9.

In the model this production function is used in a modified form to allow for time-lags in the economy's reponse to higher energy prices. This is extremely important, because most changes concerning the adjustment to higher energy costs will be associated with new equipment and structures, and the average life-time of the capital already in place might be as high as 40 years and more as in the case of housing and urban transportation systems.

In ETA-MACRO these lags are built into the production function by appropriate growth limitations relative to previous periods. These time lags are also reflected in the equation for physical capital accumulation, which is the last on in Fig. 9. To approximate a two-year average gestation lag between investment and useable capital stocks, it is supposed that 60 % of gross investment provides an immediate increase in the capital stock, but that 40 % has a five-year delay. Capital stocks (k(t)) are expanded by gross investment (I(t)) and are reduced by the capital survival fraction.

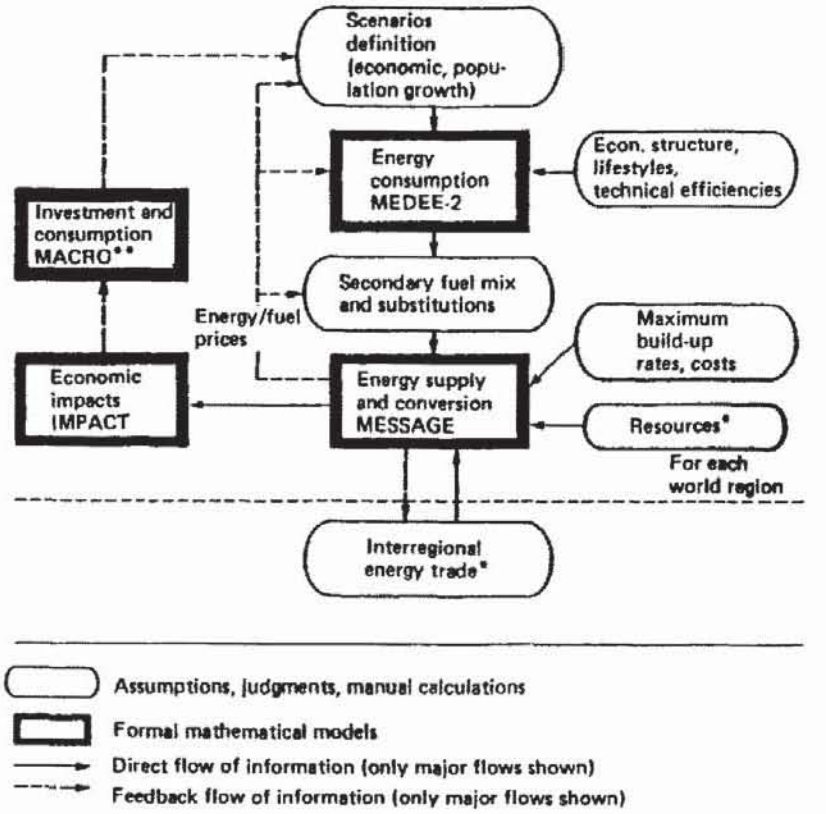
The other submodel, ETA, is a conventional linear programming energy supply model, which for a given set of resources and technologies aims at searching an optimum energy path. The degree of detail shown here, however, is much less than in energy system models of the MARKAL type. As most of the general equilibrium models which apply aggregated functions in the economic sector and look into the energy sector with less detail, ETA-MACRO is not intended to be used as a planning tool, which produces a single set of numerical results. The merits of the model have to be seen in the fact that it enables us to check the logical consistency of competing assumptions about energy futures using a clear and straight-forward approach. In fact, the model has been found to be a useful instrument to study for instance the implications which a nuclear path would impose on the US economy, and to describe the impact of higher oil prices on economic growth.

The energy modelling approach of IIASA (the International Institute for Applied Systems Analysis) /8/ is another typical example of an energy-economy model. It is designed to analyse the energy sector as an integral part of the economy.

But unlike the integrated models (PILOT, SRI, Hudson-Jorgenson, ETA-MACRO, ZENCAP) which treat the interactions between energy and the economy within a single network of equations, IIASA has created a package containing a set of various models, applying different techniques.

IIASA's energy modelling team has adopted the philosophy that the linking of several independent and simple models has advantages over large scale model blocks involving complex functional relations. The links need not be automatic, but may involve human interference.

Fig. 10 illustrates the modelling approach adopted at IIASA. Four independent models, MEDEE-2, MESSAGE, IMPACT and MACRO are used, each applying a different methodology and having a different purpose. Every single model provides inputs to the system considered, either in the form of direct input data to other submodels or in the form of general information which is used to modify assumptions. The entire modelling approach is a highly iterative one. Initial assumptions and judgements lead to calculations and results, which provide feedback information for the alteration of the inputs until convergence is achieved.



*Formal mathematical models to replace these judgmental analyses are in process.
**Not yet fully implemented.

Fig. 10: The IIASA Set of Energy Model

The start of the modelling loop is determined by the definition of scenarios as indicated on top of Fig. 10. Assumptions about economic and population growth are the main parameters for the distinction of the IIASA scenarios. Information about economic and demographic developments and judgments about lifestyle changes, improvements in efficiencies of energy using devices, and the rate of penetration of new and/or improved energy-using equipment are fed into the submodel MEDEE-2. This model determines the energy demand in terms of secondary energy for major end-use categories such as space heating/cooling, water heating, cooking in the residential and commerical sector.

The technique of MEDEE-2 is simple: most of the relationships are linear combinations of variables and the model is used as a straightforward accounting framework. The resulting secondary fuel mix together with constraints on the maximum build-up rates, cost of new energy supply and conversion facilities and resource availability constraints is then inserted into the second submodel, called MESSAGE

(Model for Energy Supply System Alternatives and their General Environmental impact). MESSAGE is , like MARKAL, a time-dependent linear programming model which provides an optimum allocation of fuels to meet a given demand. It is a dynamic model and allows the explicit treatment of interfuel substitution, which takes place over time in the energy supply and conversion sector.

The third submodel, IMPACT, is a dynamic input-output based algorithm, which determines the impacts of a certain strategy on the economy in terms of:

- Investments in energy system capacities,
- Capacity build-up in energy related sectors of industry and corresponding capital investments,
- Requirements for materials, equipment and services for construction and operation of the energy system and related industrial branches.

With IMPACT calculated costs, the economic feasibility of a strategy can be checked, e.g. whether or not energy will absorb unacceptably high portions of the economic products, or what amount of non-energy exports are necessary to compensate for energy imports etc.. Finally, the MACRO submodel calculates aggregated investment and consumption patterns based upon IMPACT provided cost data. This in turn leads to a revised computation of economic growth rates, which is checked with the original assumption and reentered into a new iteration loop.

It is this very broad concept of iterations within the computation routes which provide for consistent scenarios. If the full set of models are employed in iterations, we have in fact a general equilibrium approach for interactions between economic and energy sector activities.

IIASA's energy modelling set is not designed for energy planning purposes but aims at investigating the longer term perspectives for transitions to energy supply systems in a resource constrained world. It was applied in a well known study of the development of world regions between now and 2030 giving special attention to the different needs and possibilities of western industrialized countries, communist areas, developing countries and less developed countries /9/.

4. DECISION MAKING AND ENERGY MODELS

This is where the development and application of energy models stands today. I believe that the energy modelling community can look back upon a tremendously fast development over the last ten years. Great advances can be reported, such as:

- the development of models for many different issues in the energy policy and planning area
- the availability of large scale models of the entire energy system as well as of models that describe the interaction between the energy sector and the rest of the economy
- the availability of improved data bases and modelling techniques, as well as extremely powerful computers and modelling software.

But are these advances sufficient?

Is it not so,

- thatmost of the energy policy decisions and the strategic decisions in the energy industry arenot based on the outcome of an energy modelling analysis,
- that energy modellers do not have much to offer when complex real world problems require a quick answer,
- that the treatment of uncertainty, which during the last years has become the major issue in the planning process, is still unsatisfactory from the decision making point of view.

So what did the energy modellers do wrong? Nothing as yet, I believe. They developed a variety of efficient and powerful models in a reasonable short time. Methodological improvements are still possible, but as useful energy models are available yet, the attitudes of the energy modelling community must be shifted from the development of new and more detailed models to the application of the models to help to solve the problems the decision makers are confronted with.

Let me now outline some ideas how the situation can be improved.

The appreciation of energy models by the so called decision makers is characterized by up and downs. The initial phase of suspicion and skepticism that was based on ignorance was followed by a phase of overconfidence and high expectations. During that time the models, especially computer models were viewed to be able to provide answers to any question; to be not a tool for making up our minds, but the answer itself. As it turned out that the predictive power of the various energy models was not sufficient to be of empirical values in the light of events, overconfidence turned into disillusionment. Since some years we are in the phase of disillusionment. What is at stake now is

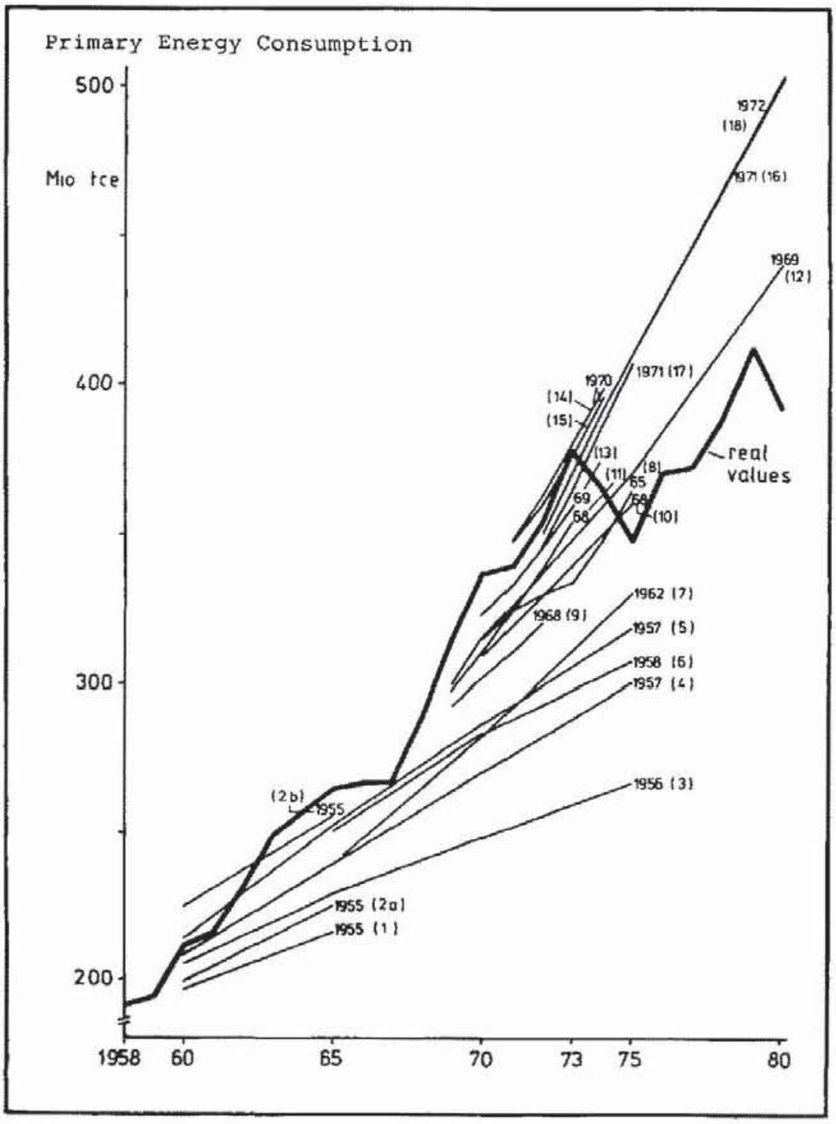


Fig. 11: Energy Forecasts (1955-1973)

to overcome the present distrust and to regain credibility. Otherwise the danger is great that energy models will never contribute to better decisions in energy policy and the energy industry.

I believe that models and modellers must adopt a more issue-oriented approach and that expectations on both sides must be reduced to what can be provided by an energy model analysis. Energy models have often been employed to provide precise numerical forecasts of the future development of the energy system. But energy forecasting is a hazardous occupation. Virtually any projection turned out to be incorrect /10/.

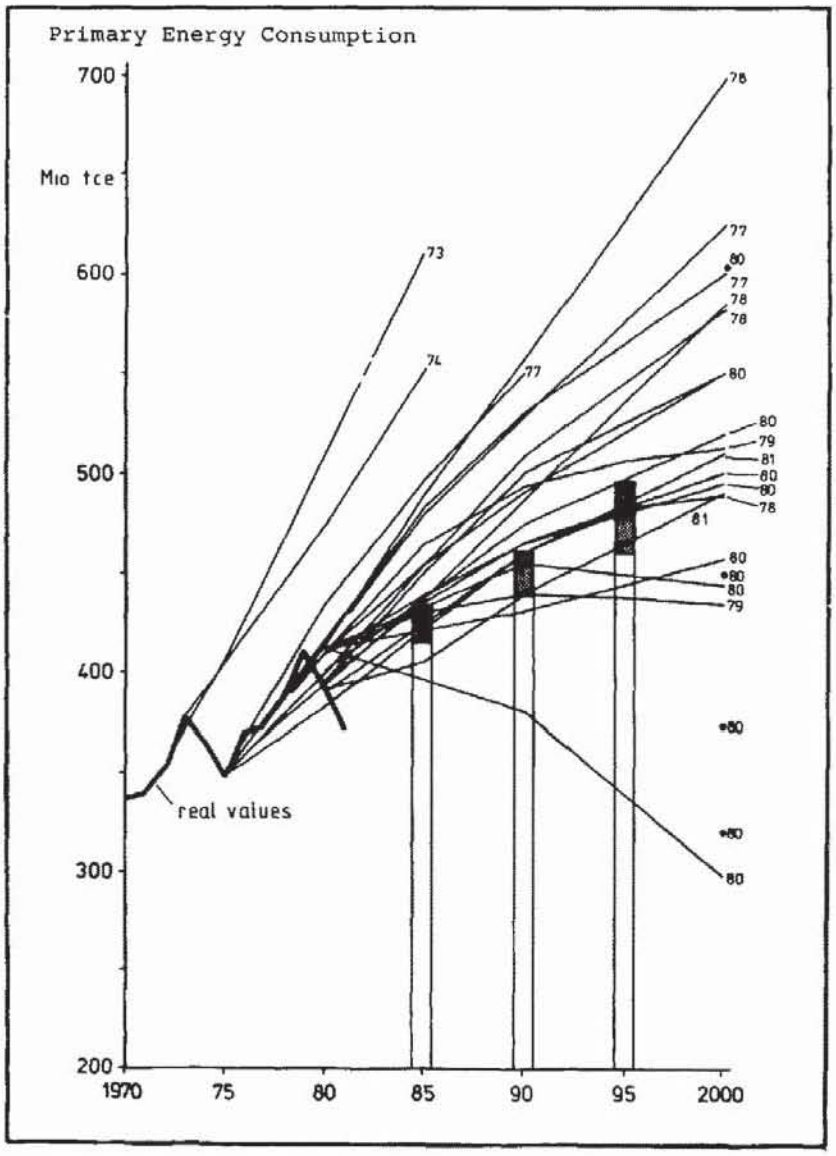


Fig. 12: Energy Forecasts (1973-1981)

Fig. 11 shows the primary energy forecast for the Federal Republic of Germany, which were published in the period from 1950 to 1972. Compared with the actual development, all forecasts turned out to be wrong. The increase of the primary energy consumption was underestimated by the forecasts of the 50's and 60's.

In Fig. 12 the primary energy forecasts published after the first oil crises in 1973 are illustrated. The figures for the primary energy consumption of the year 2000 differ by about a factor of two. Without going into further details, I think this figure demonstrates that their succes in forecasting the energy future will not be greater than that of the earlier forecasts in the 50's and 60's.

To state the point more clearly, I think that history has shown, that we can not expect any precise forecasts of the future, even if we employ very detailed and sophisticated models.

The reason for this is, that the development of the main factors determining future energy demand and supply, such as the economic growth rates or the price of crude oil, to mention only two, is to a great extent uncertain. Opinions for example about the future oil price development have changed in recent years dramatically during relatively short periods of time. The range of long term oil prices estimated published since 1973 reaches from 15 $ to 150 $ per barrel. And a recent analysis of the IIASA about the oil price estimates used in the most up-to-date long-term energy projections throughout the world showed, that the individual oil price estimates for the year 2010 differ by factor of three /11/.

Some energy modellers and energy analysisists have reacted to the increased uncertainty by generating several scenarios with different assumptions about the uncertain factors. Concerning the world oil prices uncertainty is usually reflected by assuming two or three annual growth rates, low, moderate and high. The usual recommendation to the decision maker then is: We'll give you the results under these scenarios and you make your own choice. But where does this leave the decision maker? It seem to me that this kind of analysis is not very helpful to him. If it is not possible to be more precise about the oil price development, then at least he should be provided with the information how this uncertain factors influence his near-term decisions, or with an indication of those nearterm decisions that are insensitive to these assumptions.

For the use of energy models this does mean, that rather asking what the energy demand in some future year will be, or what the contribution of different supply options in the year 2000 will be, the appropriate question is, what must an energy policy look like, if it has to be robust and flexible enough to cope with the uncertanties that lie ahead?

If energy models are to aid in decision-making, then it cannot be a meaningful aim to try to forecast the future development of the energy system. However carefully the forecast is made, the inherent uncertainty lying in the future cannot be removed. Rather the task consists in identifying with the help of the energy model and after explicit consideration of the uncertainties, what I would like to call "robust" decision steps. These are those steps relevant to the near future, that give the best possible guarantee, that the path chosen will not have been regretted at a much later point of time /12/.

I believe, that this different view of how to use energy models to provide useful information to the decision making process is a prerequisite to regain credibility and promote a more fruitful interaction between the decision makers and the model builders.

Models in general and energy models specifically should not be viewed as tools, that will predict the future more accurately. But with models we may be able to understand better the interdependances and influences of various factors - both, those that are within our control and those that are not. Making use of these potential benefits of energy models requires, that they are viewed by both the energy modellers and the decision makers as tools for developing insights rather than for forecasting numbers.

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