A Review of Energy Models. No. 1 (revised September 1976)

Charpentier, J.-P.

IIASA Research Report
May 1974

RR-74-10

A REVIEW OF ENERGY MODELS

No. 1 - May 1974

(Revised September 1976*)

Jean-Pierre Charpentier

*The errata of the previous versions have been corrected in this edition.

A REVIEW OF ENERGY MODELS:

No. 1 - May 1974

With Contributions* by:

D. Elsinghorst,	Kernforschungsanlage,	Jülich, F.R.G.
J. Girod,	IEJE, Centre National de la Recherche Scientifique,	Grenoble, France
R. Treitel,	INSTN, Commissariat à l'Energie Atomique,	Paris, France
A. Voss,	Kernforschungsanlage,	Jülich, F.R.G.

---

*The authors are much indebted to Mrs. T. Koopmans (IIASA) for her efficient help, to G. Friede (Kernforschungszentrum, Karlsruhe), whose studies have unfortunately been interrupted due to illness, and to V. Landauer and A. Weingaertner for their very faithful secretarial assistance.

TABLE OF CONTENTS

Introduction 1

Classification of Models 6

List of Models 7

Models Class A 11

Models Class B 43

Models Class C 47

Models Class D 63

Models Class E 64

Models Class F 76

Annex I: Bibliographical Details of Models 80

Annex II: Persons and Institutions Contacted 87

Introduction

(Oral presentation at the Working Seminar on Energy Modelling
May 28-29, 1974, International Institute for Applied Systems Analysis)

There is an obvious correlation between the number of energy models and the impact of energy problems. The activities of energy modelists have been unsuccessful in the prevention of the present so-called "energy crisis." For a clear formulation of the problem, we envisage energy modelling to be the efficient contributing factor.

Our aim in presenting this first collection of summaries of energy models is both simple and ambitious: we hope that everyone who studies the energy problem and wishes to resort to models can see at a glance whether a tool exists anywhere in the literature which could be applied to his special set of problems, thus eliminating the search for further information and avoiding duplication of effort. This would also permit the establishment of contacts and collaboration between specialists concerned with energy problems independently of and beyond political considerations.

On the occasion of this meeting we have prepared a first collection of models (though incomplete) in order to benefit from your "on the spot" expertise, which will be invaluable for the forthcoming publication.

The models for this first review have been selected along the following lines:

1) Only models less than 5 years old have been taken into account. Some are still in the stage of development, and results are given only for some aspects of the model; in our opinion they are sufficiently interesting and promising to be included in this review.

2) Models dealing with the management of energy producing and distributing organizations generally have not been included; these will be considered in a later version of the review.

The majority of the models in this compilation have not been reviewed by their authors; this was due to the time factor. We are aware that this may cause misunderstandings and ask the authors for their forbearance. At a later date we plan to incorporate only models that have been summarized by the authors themselves.

We plan to publish a survey of models annually, which will include both new models and updated versions of those described earlier. We hope that this first review will generate enough interest among model builders to encourage them to help us in this task.

As we are mainly concerned with energy problems, the standard summary we have used focuses more on the field of applications of models than on the methodological aspects. Furthermore, our intention is to deformalize somewhat the definition of the term "model." It is used for any kind of tool (methodological or otherwise) necessary for problem-solving, and only the feasibility and usefulness of the model are of interest.

Originally we intended to distinguish between complex econometric models, simple ones which use correlations, and the new kind of model that only takes into account subjective expert opinions. This approach has been discarded since we feel that the results obtained are more important than the methods by which this is done. This is why the term "model" includes, for example, a study which constitutes only an extension of the input-output matrix that estimates the amount of energy contained in various manufactured products (study of Herendeen, U.S.A.). In order to avoid value judgments that might be biased or are not fully supported by facts, we have not used a classification based only on the methodological aspect of a model.

The models described in this review are classified according to the following 6 categories:

Classification of Models

Areas of Application		National	International
Energy System (energy is the main problem)	one kind of fuel	A	B
	several kinds of fuel	C	D
Linkage between energy and general economy		E	F

This classification is based on our impressions of the model users' most important requirements.

We have attempted to cover various countries, and in so doing have benefited from personal contacts with a substantial number of specialists in various fields. These contacts have been established partly through IIASA; we are particularly indebted to the U.N. Economic Commission for Europe (Geneva) for giving us the opportunity of making other valuable contacts.

A complete list of the institutions and individuals we have contacted is attached to this report (Annex II), and we would greatly appreciate any additional contacts for our mutual benefit.

Let us now look at the standard form we have developed for the model summaries. It may appear arbitrary; however, in the search for criteria for the evaluation of a model, this breakdown may become clearer.

What is a "good" model (noting that this is a subjective notion)?

1) A model that permits us to reach certain fixed goals or objectives;

2) A model that, in terms of efficiency, is better suited for the goals than any other model available.

In our standard form, we therefore describe the Subject and Goal of the models immediately after the authors' names, their affiliations, and the (sometimes shortened) model titles. (Bibliographical details are given in Annex I. Where they are incomplete, we shall try to rectify this in future editions.) This is followed by Systems Described, in which we give a general idea of the approaches used and the complex interactions within the system.

After this general outline of the authors' goals and the system studied, we try, in the sections Modelling Techniques and Input Data, to make a clear distinction between what is endogenous and what is exogenous. Modelling Techniques describes all logical aspects of the model--i.e. the main concepts which explain the internal structure of the mathematical representation--without treating the mathematics itself.

For each model selected we have tried to give an idea of the volume of the input data and to distinguish what is exogenous, although this notion is not always clear in the original papers. For reasons of space we have not specified quantitatively the value of data; however, we are aware that this is often as important as the model itself. I believe that it would be very useful if in each country model builders and energy experts came to some agreement on certain data bases. It would not be difficult to identify the useful available data; for example, in many U.S. models several authors make use of the same data bases.

In Output Data we merely indicate the kind of results given by the model. The quantitative values supplied by each model are often too large to be incorporated in such a summary. Finally, Observation is devoted mainly to possible future development of the models.

Despite its incompleteness, this review indicates the differences between the native countries and intellectual origins of the models. Naturally, the first countries to build models that explicitly include the energy system are those with more or less planned economies, where the question of energy is concentrated within a small number of ministries. Countries with free market economies which, as a group, initially lagged behind in energy modelling have made up for it in recent years. In the United States in particular, an important development of different kinds of models has taken place. The acceleration of this development can be explained by the American system, in which studies of crucial problems are often delegated to universities or other groups. Therefore, it appears that the ever-increasing number of models is, in part, a result of the competition for financial support from governmental agencies and foundations. More precisely, the models published are approximately equal in proportion to the enterprises immediately concerned, or governmental institutions, universities, and independent think tanks.

Until now Western European universities have played a less dominant role, as links between universities and decision-makers are weaker in Western Europe. The lack of good data banks is another reason for this difference. Most of these models have been supplied by governmental agencies or the companies concerned.

These observations in part explain two facts:

1) There are more models from the U.S.A. and the U.S.S.R. than from Western Europe.

2) Most of the models from Western Europe are in the nature of management models for public utilities, and are not directly concerned with the energy system as a whole.

Nevertheless we can observe a very interesting trend toward a new kind of model. Until recently many models considered investment problems linked to one form of energy (mainly electricity). Such models seem to be well known in the U.S.A. as well as in the U.S.S.R.; most of them use a very efficient development of linear programming. In addition, notice should be taken of certain new models that include optimal control theory, for example, those developed by the Electricité de France or in the U.S.S.R.

At the present time authors seem to be interested in wider areas and more extensive systems. They either study all the energy problems of one country, or they investigate the trade problem of one kind of fuel on an international scale. In the first category two kinds of approach are pursued:

i) All kinds of fuel are studied in energy-sector-wide models, including the supply and demand levels e.g. Dr. Hoffman's model, in which he studies the optimization of the U.S.A. energy network at different times, including the problem of new technologies; and the large-scale systems being developed in the U.S.S.R.).

ii) The other approach consists of a linkage between different submodels, each of which is concerned with one type of fuel (consider, for example, the approach by Dr. Hutber, U.K.).

In the second category, new models on world trade, the study of the world petroleum market is a main concern. In this area two models appear very promising: namely, those developed by Prof. Deam, U.K., and Prof. Houthakker, U.S.A., each investigating the consequences of different energy policies.

Let us note that the study of new technologies in itself has become the subject of models. I cite the work pursued at IIASA by Profs. Häfele and Manne on the possibilities of the interactions of fast breeder reactors, and of an economy based only on nuclear fuel. Within this category the model by Prof. Just, U.S.A., is also interesting in its approach to the financial impact of forthcoming techniques of gasification and liquefaction of coal.

We have observed that a weakness seems to exist in the link between economic concepts and the energy system, which becomes particularly apparent in the treatment of demand, pollution, or more general environmental problems, and the impact of R&D.

Most demand studies are based upon forecasting techniques such as trend extrapolation or regression analysis, correlating demand with variables such as G.N.P. per capita. In view of the value of certain parameters, such as elasticity with respect to income or price, not being generally accepted, some authors seem to be reluctant to incorporate this concept into their models. More emphasis on this subject would be worthwhile.

The problem of pollution is practically always dealt with in somewhat superficial terms. From a physical point of view these effects are usually treated in the form of a simple multiplication of the amount of energy produced by specific pollution factors. The result of this operation gives the aggregate volume of emissions without considering the local impact of pollution on the welfare of man. This procedure leads to a study of only the economic aspects of pollution; very rarely does it extend to e.g. feedback from negative effects of pollution on human welfare.

With respect to attempts to model the effect of the R&D effort on the solution of energy problems, to date there are not enough tools available. Some models take new technologies into account, but they usually incorporate a random date of availability after having made some assessments of the potential of these new technologies. No model among those considered really investigates the impact of R&D on society, or what need there is to continue to spend money in order to obtain a better knowledge of, for example, fission, solar, geothermal, and fusion energy.

Finally if we take into account the objective functions used in optimization models, it seems that authors are generally content with traditional concepts and seldom look for innovation. In fact, the objective function most frequently employed is inevitably the minimization of the discounted costs required for a given level of demand. It is evident that the minimization of total costs is not always the only objective of utilities or governments.

In long-term forecasting it is quite clear that a more refined objective must be considered. We could ask ourselves whether the models actually developed could be useful in this respect. I should like to leave this question open for discussion.

It would not be feasible for us to try to give answers to this short list of complex questions. This is why some of them have been summarized and presented to you in the form of possible suggestions for the afternoon discussions.

The four main subjects, in brief, are as follows:

- The first concern is the general problem of energy modelling: projection, optimization or games models.
- The second is the formulation of demand relations.
- The third is the modelling of the R&D impact.
- The fourth is the integrating of energy models into an economy-wide model and the linking of several models.

The great number and variety of models now being developed will increase our knowledge of the economic mechanisms of the energy sector. At the same time new developments in other fields or systems will present new kinds of sophisticated tools of use in our research. Note must be made, however, that in addition to these innovations it is desirable to establish more coordination among models and a common broad line of research along which they could be developed.

That is why it is so important today that energy specialists and modelists have come together to work out and perhaps define an overall strategy. It is hoped that this review of energy models may help to add and clarify information and in this way promote a fruitful exchange of ideas.

Classification of Models

<table>
<tr><th colspan="2">Areas of Application</th><th>National</th><th>International</th></tr>
<tr><td rowspan="2">Energy System (energy is the main problem)</td><td>one kind of fuel</td><td>A
32*
(pp. 11-42)</td><td>B
4*
(pp. 43-46)</td></tr>
<tr><td>several kinds of fuel</td><td>C
16*
(pp. 47-62)</td><td>D
1*
(p. 63)</td></tr>
<tr><td colspan="2">Linkage between energy and general economy</td><td>E
12*
(pp. 64-75)</td><td>F
4*
(pp. 76-79)</td></tr>
</table>

*Number of models in this class

List of Models

Country	No.	Title	Class	Page
Austria	AU 1	Austria II, J. RICHTER & W. TEUFELSBAUER	E	64
"	AU 2	Consequences of a possible energy crisis in Austria, G. TINTNER	C	47
Canada	CA 1	Model for energy supply vs. pollution, J.G. DEBANNÉ	C	48
"	CA 2	Estimating and forecasting model of natural gas demand, P. HALPERN & L. WAVERMAN	A	11
"	CA 3	Demand for gasoline and automobiles, D. DEWEES & L. WAVERMAN	A	12
"	CA 4	Econometric model for energy, INSTITUTE FOR POLICY ANALYSIS (L. WAVERMAN)	C*E	49
"	CA 5	Residential and commercial demand for energy, R. HYNDMAN	C	50
"	CA 6	Linear programming transportation models, L. WAVERMAN	C	51
C.S.S.R.	CS 1	Electric power system expansion, R. FREIBERGER et al.	A	13
"	CS 2	Prediction of SO_2 and flyash emission, P. KOPAC & E. HAZUKA, F. LIDICKY et al.	A	14
"	CS 3	Electric power system development, I. LENCZ	A	15
"	CS 4	Development of an electric network, E. KREJCOVA, S. PACAK, S. KRIZ & V. ZAPLETAL	A	16
"	CS 5	Structural model of fuel and energy economy, B. CABICAR et al.	C	52
Denmark	DE 1	Alternative organizations of society in terms of energy use, S. BJØRNHOLM	C	53
Finland	FI 1	Production planning and the new technology, E. RAUTOMA, M. SOURANDER et al.	A	17
France	FR 1	FINER, energy financing model, D. BLAIN	E	65
"	FR 2	PANACH, simulation model of the nuclear fuel cycle, J.P. CHARPENTIER, G. NAUDET & R. PAILLOT	A	18
"	FR 3	MEXICO, electrical network transport, J.C. DODU	A	19

*Model can be associated with either class.

Country	No.	Title	Class	Page
France	FR 4	MIC-MAC, hierarchical organization of the elements of a system, J.C. DUPERRIN & M. GODET	A*E	20
"	FR 5	Choice of production investments at E.D.F., A. BRETON, D. LEVI & D. SAUMON	A	21
F.R.G.	FG 1	Development of power plants in Nordrhein-Westfalen, R. BIESELT	A	22
"	FG 2	ENIS information system for the energy sector, ZENTRUM BERLIN FÜR ZUKUNFTSFORSCHUNG, J. BÜRSTENBINDER, W. DREGER, H. ILLING, F. OPALLA and P. ROSOLSKI.	C	54
"	FG 3	Econometric models for the energy sector of the F.R.G., M. LIEBRUCKS	C	55
"	FG 4	RESTRAPRO, reactor strategy program, W. MEIER & A. VOSS	A	23
"	FG 5	Long-range expansion of a power system, G. MEURIN	A	24
"	FG 6	Electricity utility model, H. TRÖSCHER	A	25
"	FG 7	Analysis of the system man-energy-environment, A. VOSS	F*D	76
Hungary	HU 1	Investment policy in the energy economy, F. RABAR	C	56
Ireland	IR 1	Price increase of imported fuels, E.W. HENRY & S. SCOTT	E	66
Japan	JA 1	Growth of nuclear power, INSTITUTE OF ENERGY ECONOMICS (M. SAKISAKA)	A	26
"	JA 2	Simulation of future oil flow, INSTITUTE OF ENERGY ECONOMICS (M. SAKISAKA)	B	43
"	JA 3	Optimizing energy allocation to industrial sectors, INSTITUTE OF ENERGY ECONOMICS (M. SAKISAKA)	E	68
"	JA 4	Long-term energy demand in Japan, INSTITUTE OF ENERGY ECONOMICS (M. SAKISAKA)	E	69
"	JA 5	Energy utilization in the future, K. OSHIMA	E	67
Poland	PO 1	Nuclear power system optimization, M. BERNATOWICZ	A	27
"	PO 2	System of two-component nuclear power, J. PODPORA	A	28
"	PO 3	Power plant system with variable load factors, W. FRANKOWSKI	A	29
"	PO 4	Power plant system development, W. FRANKOWSKI	A	30

Country	No.	Title	Class	Page
Rumania	RO 1	Multi-energetic supply model, M. PETCU, PAP, KOVACS & LICIU	C	57
Sweden	SW 1	Multi-period cost minimization model for Sweden, G. BERGENDAHL	A	31
"	SW 2	Energy supply and demand forecast, E.S. BEN SALEM & M. HÖJEBERG	A	32
"	SW 3	SVEN - Swedish Economy 1970-1977, B.O. KARLSSON	E	70
Turkey	TU 1	Investment in the electricity supply industry, O. TARKAN	A	33
U.K.	UK 1	World energy modelling: concepts and methods, ENERGY RESEARCH UNIT (R.J. DEAM, M.A. LAUGHTON, J.G. HALE, J.R. ISAACS, J. LEATHER, F.M. O'CARROLL, P.C. WARD)	B	44
"	UK 2	Development of Western European oil prices, ENERGY RESEARCH UNIT (R.J. DEAM, M.A. LAUGHTON, J.G. HALE, J.R. ISAACS, J. LEATHER, F.M. O'CARROLL, P.C. WARD)	B	45
"	UK 3	U.K. national energy model, MODEL GROUP OF THE DEPARTMENT OF ENERGY (F.W. HUTBER)	C	58
"	UK 4	Simulation of a nuclear generating system, C.E. ILIFFE	A	34
"	UK 5	Electricity supply model, F.P. JENKIN	A	35
"	UK 6	Tradeoff between energy and GNP, L.G. BROOKES	E*F	71
U.S.A.	US 1	Tradeoff between energy and GNP, F.G. ADAMS & P. MIOVIC	E*F	71
"	US 2	Dynamic energy system modelling - interfuel competition, M.L. BAUGHMAN	C	59
"	US 3	SRI energy modelling capability, E.G. CAZALET	C	60
"	US 4	Substitution and usage in energy demand, E.W. ERICKSON, R.M. SPANN, R. CILIANO et al.	C	61
"	US 5	Use of I/O matrix, R.A. HERENDEEN	E	72
"	US 6	Planning framework for energy system planning, K. HOFFMAN	C	62
"	US 7	Energy demand as a function of price, H. HOUTHAKKER & M. KENNEDY	A*E	36
"	US 8	World petroleum model, H. HOUTHAKKER & M. KENNEDY	B	46
"	US 9	Energy analysis using I/O matrix, J.E. JUST	E	73

Country	No.	Title	Class	Page
U.S.A.	US 10	Policies for dealing with the natural gas shortage, P.W. MacAVOY & R.S. PYNDICK	A	37
"	US 11	Waiting for the breeder, A.S. MANNE	A	38
"	US 12	California's electrical energy demand, W.E. MOOZ	A*E	39
"	US 13	Allocation of energy resources, W. NORDHAUS	D	63
"	US 14	Dynamic model of energy and economic growth, R.J. RAHN	E	74
"	US 15	Relationship between macroeconomic activity and energy consumption, P.K. VERLEGER	E	75
U.S.S.R.	UR 1	Energy consumption forecasting, I.N. BESSONOVA, N.S. KULENOW, Z.H. HASENOV & S.C. CHOKIN	A	40
"	UR 2	Power industry models, A.I. MEKIBEL & T.M. POLYANSKAYA	A	41
Various sources	X 1	International linkage of national economic models, INTERNATIONAL STUDY GROUP ON THE LINK SYSTEM (L.R. KLEIN)	F	77
"	X 2	Nuclear power market in developing countries, TEAM OF INTERNATIONAL ATOMIC ENERGY AGENCY STAFF MEMBERS	A*F	42
"	X 3	Energy models of the multilevel world model project, M. MESAROVIC & E. PESTEL	F	78
"	X 4	Integrated energy models for the CEE, R. de BAW & F. VAN SCHEEPEN	F	79

MODELS CLASS A

CANADA

The Model		Paul Halpern and Leonard Waverman, University of Toronto. Estimating and Forecasting Model of Natural Gas Demand.
Subject and Goal		Showing divergence between good estimating models (i.e. one which approximates behaviour) and good forecasting models.
System Described		Natural gas.
Area	Time	Cross section time series.
	Space	Canada.
Modelling Techniques		Econometrics.
Input Data		Demand vector, price of natural gas and substitutes, income.
Output Data		- Elasticities of demand. - Projections of demand, given forecasted prices and income.
Observations		Techniques will be applied to all fuels.

Summary supplied by the authors of the model.

CANADA

The Model		Don Dewees and Leonard Waverman, University of Toronto. Demand for Gasoline and Automobiles.
Subject and Goal		The end product will be a simultaneous forecasting model which projects the demand for new cars, their characteristics and the derived demand for gasoline.
System Described		Interrelationships between the price of gasoline and the number and type of autos purchased.
Area	Time	Time series.
	Space	Canada, can be applied anywhere.
Modelling Techniques		Non-linear simultaneous equation econometrics.
Input Data		Vectors of: gasoline sales, price of gasoline, income, automobile registrations (number and characteristics, supply of substitutes to private auto), and prices, trip time, variable and fixed costs of auto use.
Output Data		Outputs will be forecasts of auto sales and type and gasoline use.
Observations		Present working model is an examination of gasoline use as a function of prices, income and characteristics.

Summary supplied by the authors of the model.

C.S.S.R.

The Model		R. Freiberger et al., 1968-1973[1,2,3,4,5], Energy Research Institute, Prague. Electric Power System Expansion.
Subject and Goal		Selection of an optimum structure of electric power and energy sources (medium- and long-term); prognostic functions of electric energy consumption are part of the model. Goal of the computations is to ensure the coverage of prospective annual consumption of electric energy and power on the day of annual load maximum at minimum power production cost.
System Described		A developing power system: the prospective load (on the day of annual maximum) is divided into regime bands of the model, allowing sufficiently accurate representation of some non-linear relations (e.g. between fuel consumption and the load of individual power plant types) by linearization in parts. For each regime band load is fixed according to the annual maximum load of the system and the annual energy of each regime band (given by the annual load duration curve). Another band is added (annual hourly maximum), representing power requirements for covering the difference between hourly and short-term (5 or 15 minutes) load maximum The model selects, from a list of resources containing existing and possible additive power stations, the coverage of power and energy requirements (including reserve requirements) with due regard to the given set of restraints.
Area	Time	The model is dynamized (generally formulated for any number of time steps). It is used in practice for a prospect of 20 years (in 4 time periods).
	Space	The model is multi-nodal (theoretically for any number of regions). So far it has been used as one-node or three-node model.
Modelling Techniques		Mixed integer programming - simplex algorithm and the branch and bound algorithm for new sources with a small number of high rated units and groups of hydraulic power plants linked hydraulically). Objective conditions are minimization of the sum of costs discounted to the initial year, through the last years of all dynamically linked periods through all regime bands, all regions and all kinds of sources.
Input Data	Physical	- Prospective requirements of power and energy for individual regions and time periods - in probabilistic form - with a given index are determined with respect to the macroeconomic optimum based on the regression relations between national income and electric requirements. - Sources of electric power and energy - for existing and considered power plants. - Standard basic technical indices (e.g. electrical output, annual number and duration of shutdowns for overhauls and repairs, average frequency of failure shutdowns, fuel consumption characteristics of individual kinds of sources, kinds of primary energy sources). - Fuels for electric energy production - probable available quantities of fuel for electric power production for certain future years, the fuels are divided according to their origin; data on calorific value, sulphur content, etc. - Transmission grids, energy and power losses by transmission.
	Ecological	Limitations of installed output in individual regions due to the condensing power plants' emissions and limited cooling water supplies.
	Economic	- Sources of electric output and energy - economic data are included in the standard questionnaires (specific capital costs, repair costs, fault removal costs, wages). - Fuels for electric power production - extraction and treatment costs for individual kinds of fuels, transportation costs from mines to power plants. - Transmission grids - specific capital costs analogous to the variable cost components due to transmission equipment operation (in first approximation).
Output Data	Physical	- Coverage of regime requirements, including load on the day of annual maximum, and annual energy. - Annual supply of electric energy (also between regions). - Installed capacities of individual kinds of sources. - Utilization of the installed capacities of individual kinds of sources. - Shutdown and reduced output of individual sources and total reserve power of the system. - Annual consumption of fuels divided according to kinds of power plants and fuels.
	Economic	- Value of investments in electric power and fuel bases. - Capital costs of newly installed facilities corresponding to various fuel bases, always for the given period. - Annual costs of electric energy production.
Observations		- From the primary input data a service program computes input data for the model (matrix coefficients, vector of the right sides of the constraints, vector of coefficients of the objective function). - When optimization computations are completed a service program computes output data as required in a standard table form. - The model contains 14 basic types of constraints. - The formulation of variants is performed by: 1- the change of the right side of the constraints (mainly limitations in possible development of new types of sources and in quantities of individual kinds of fuels); 2- the change of the objective function coefficients - for changes in specific capital costs of various types of equipment and of fuel costs.

Summary supplied by the author of the model.

C.S.S.R.

The Model		P. Kopac and E. Hazuka [6], F. Lidicky et al., 1974 [7], Energy Research Institute, Prague. Prediction of SO_2 and Flyash Emission.
Subject and Goal		Quantification of SO_2 and flyash emissions from the viewpoint of: energy process, kind of fuel, territorial region, year. Operative evaluation of the consequences of studied variants of the long-term development of the energy economy for air cleanliness.
System Described		SO_2 emission calculation: the system is formed by 12 aggregated energy processes realized in 10 territorial regions. There are in total 24 kinds of fuels due to different sulphur content. Flyash emissions calculation: the system is formed by 8 energy processes realized in 10 territorial regions. There are in total 14 kinds of fuels due to different ash content.
Area	Time	Static calculation model for individual years. The model has been used for the years 1970, 1975, 1980, 1985, 1990.
	Space	Ten territorial regions in the C.S.S.R. and their combinations.
Modelling Techniques		Basic equations for SO_2 and flyash emission calculations according to the above four viewpoints are solved by means of the matrix calculus. The calculation is performed by computer.
Input Data		For the SO_2 emission calculations the energy processes are distributed as follows: - extraction and treatment of fuels (1 process) - refining of fuels (3 processes) - energy conversion (4 processes) - final consumption of fuels and energy (4 processes) For the flyash emission calculation only the processes of energy conversion and final consumption are included (8 processes) These processes must be characterized by the following data: - annual production or input or consumption of an individual kind of fuel (10^6 t/year) - emission factor for each process-fuel combination. For the SO_2 emission calculation the individual kinds of fuel are distributed as follows: - solid fuels (16 kinds) - liquid fuels (6 kinds) - gaseous fuels (2 kinds) For the flyash emission calculation 14 kinds of solid fuels are considered. The kinds of fuel must be characterized by the sulphur or flyash content.
Output Data Ecological		SO_2 or flyash emission values for the following combinations of viewpoints: - process (groups of processes) x territorial region and year - fuel (groups of fuels) x territorial region and year - summary of the above emission values for larger territorial regions, e.g. Czechoslovak Socialist Republic. For a given year, 663 resulting values of SO_2 emissions and 429 resulting values of flyash emissions are available.
Observations		In connection with this calculation model an optimization model, to be tested in 1974-75, is being prepared; its goal is the minimization of the negative consequences of SO_2 and flyash emissions.

Summary supplied by the authors of the model.

C.S.S.R.

The Model	I. Lenez, 1969[8,9], Energy Research Institute, Prague. Electric Power System Development.
Subject and Goal	The subject of a model solution is electric power system development in a long- or medium-term time perspective. The aim is to end the economically optimum generating basis and transmission network.
System Described	A technical and an economic system split up into the subsystem of electricity generation, transmission and consumption. Interactions with the subsystems of the environment mainly those of fuel supply and water sources, are considered, as is the interaction with interconnected electric power systems.
Area – Time	15-20 years.
Area – Space	Electric power system divided, if required, into a number of regions.
Modelling Techniques	A model system using linear programming for arriving at solutions near the optimum, as well as a set of simulation models for detailed technical and economical testing of a limited number of variants (cf. Observations).
Input Data Physical	- Subsystem of electricity consumption: data on the parameters of the stochastic process of electricity consumption development (component of trends, cyclic components, random component). - Subsystem of electricity generation: existing generating sources and those planned for the perspective period, data characterizing their electric parameters, their unavailability rate, demands for planned repairs and consumption characteristics of generating units. - Subsystem of transmission: configuration and electric parameters of the initial network, alternative connection schemes and electric parameters of the planned transmission devices.
Economic	- Subsystem of consumption: costs (losses) originating from the non-delivery of 1 kWh of electricity. - Investment costs and a constant component of operating costs connected with the building and operation of power plants, schemes for financing during building, specific fuel costs, etc. - Subsystem of transmission: investment costs and a constant component of operating costs connected with the building and operation of transmission devices, schemes for financing during building. - Subsystem of environment: limits of primary energy sources, export and import of electricity.
Output Data Physical	- Information characterizing the optimum structure of the generating basis of the system (participation of individual types of power in the total installed capacity) and the development of this structure with time. - The development trend of power supply reliability in the perspective period or the development of reserve power necessary for attaining a certain chosen index of system reliability. - The optimum standard daily load curves during the optimization period; optimum distribution of annual energy generation among the individual types of power plants; consumption of fuels. - The development of transmission networks corresponding to the chosen structure of the generating basis and to alternative dislocations of sources.
Economic	- Flow of investment costs of the development of the generating basis and transmission networks (divided among the individual types of equipment). - Flow of a constant component of the operating costs of the generating basis and of transmission networks. - Flow of fuel costs.
Observations	The optimization of electric power system development is solved by means of a set of interacting models in which the initial prognostic information undergoes a progressive transformation. The procedure may be split up into the following stages: - A linearized optimization model of the electric power system as a whole, participation of the individual types of sources near the optimum being determined from the point of view of the total cost development and operation of the system in the perspective period; - A simulation model of the generating basis development generates tactical alternatives which develop the results of the linearized model in time. The reliability of the electric power system is tested and the terms of putting new generating units into operation are fixed; - For the generating basis given by the preceding model, operation of the electric power system is simulated and the role of individual types of power plants in the system is considered. Fuel costs, the consumption of individual fuels and the probable magnitude of the undelivered energy are evaluated and a nodal balance of the electricity is determined; - Based on these nodal balances, there is the development of transmission networks required for transport of electricity from the point of generation to the center of consumption; - The development tactics investigated are given a complex economic evaluation based on the dynamic criteria of economic effectiveness.

Summary supplied by the author of the model.

C.S.S.R.

The Model		E. Krejcova and S. Pacak, 1969(10); E. Krejcova et al., 1971(11,12); S. Pacak, 1974(13); V. Zapletal and E. Krejcova, 1973(14); CIGRE. Development of an Electric Network.
Subject and Goal		The program can solve elementary and special questions of topological configuration of the electric power system for a given time: - Connection of new power plants; when necessary also the choice of suitable sites from the point of view of network configuration. - Choice of links between electric power systems at different voltages; when necessary also the choice of sites for new transformer substations. - Choice of an economically optimum configuration vs. the minimum necessary extent so that the system may fulfill its transmission or distribution function.
System Described		The transmission or subtransmission electric system to be proposed for future development.
Area	Time	Period under study: an arbitrarily chosen period in the future; the parameters of the solution are related to e.g. 1 year.
	Space	Number of nodes in the system $\leq$ 150, number of branches in the system $\leq$ 300, number of voltage levels $\leq$ 5.
Modelling Techniques		The program selects, from the elements predicted for solving the partial problems of the system, a combination which leads to the minimum or next-to-minimum value of the economic function. The economic function contains the fixed annual costs (charges, service and maintenance costs) and the annual cost of power and energy losses. The inverse principle used consists in the successive elimination of lines or groups of lines. The order of elimination is so arranged that it leads to a maximum reduction in the economic function in each optimization step. During successive simplification of the system, additional constraints are tested i.e. overload of elements, unacceptable isolation of nodes, disconnection of the system, etc. The power flow calculation is made by a method corresponding to the direct current laws (the Gauss-Seidel iterative method).
Input Data Physical		The balances at the nodes, topological data of the network, resistances, reactances and the maximum permitted loading of lines and transformers; also data concerning the elements and groups of mutually dependent elements, minimum orders of the nodes.
Ecological		Minimum and maximum number of parallel branches between the 2 nodes.
Economic		Costs of 1MW lost, fixed costs of branches and surcharges on substation equipment during the period under study.
Output Data Physical		A detailed configuration of the electric power system, distribution of the flow of active power in lines, power losses.
Economic		Value of the economic function, fixed costs and costs of losses during the period under study.
Observations		- The method chosen is heuristic. - It is possible to introduce reliabilty requirements by modifying the input conditions. Nevertheless, the quantitative evaluation of reliability should be carried out separately. - The results furnished by the MDF (MAX) program have a static character, but they can also serve as a basis for dynamic planning by repeating the optimization cycle from the final stage to the beginning of the period in question.

Summary supplied by the authors of the model.

FINLAND

The Model	E. Rautoma, M. Sourander et al., 1974[15], Co. Neste Oy, Helsinki. Production Planning and the New Technology.
Subject and Goal	Planning of optimal production strategy of oil and petrochemical products in Finland in the long and short term. Includes consumption, manufacturing, import and export, as well as a description of new process units of which the most economic are selected and capacities optimized to meet future demand. The model also gives an optimal product quality and raw material specification pattern.
System Described	Mainly three types of models are used for different planning purposes: - long range planning model - time staged short range model - short range planning model. These models deal with the problems of optimal production in Neste Oy from different points of view. Various production and construction alternatives are evaluated and the optimal ones selected by the models to meet the demand.
Area	The models are steady-state models for a pre-selected time interval, except that for time staged short range planning: this is dynamic and contains 6-12 time stages for optimal scheduling of production plans. Time intervals: - long range planning model 1-10 years - short range planning model 1 month. These models contain a complete description of oil and petrochemical activities in Finland, reflecting also some non-domestic activities.
Modelling Techniques	The models are optimization models using linear programming via matrix generation. The objective function mainly used is the net profit before fixed costs. The following constraints must be satisfied: - Demand for all oil and petrochemical products must be satisfied either by domestic production or by imports - Product quality specifications must be complied with - Export restrictions must be followed - Supply restrictions of raw materials must be observed - Regional consumption must be satisfied by transport - Storage requirements are given. Each production unit has a given capacity, a variety of different yield patterns, fuel and utilities consumption and other process characteristics. The requirements of process unit capacities must also be satisfied. These models contain a detailed description of 2 refineries, 1 refinery extension, 1 hypothetical refinery, 1 olefin and petrochemical production complex, 1 power station, and 10 marketing and storing regions, as well as total import, export and consumption descriptions.
Input Data Production	- Yields and capacity of every production unit. - Utilities (fuel, steam, electricity, water, chemicals, catalysts, etc.); consumption of every production unit. - All possible feedstocks of each production unit. - Properties of each component. - Specifications of each product. - Storage capacities and starting storage inventory of each product and all raw materials. - Allowed use of blending chemicals.
Consumption and Marketing	- Consumption estimates for all oil and petrochemical products. - Import and export restrictions on products and raw materials. - Marketing information of each marketing area.
Economic	- Selling prices of all oil and petrochemical products in each marketing area. - Purchasing prices of all raw material and imported products. - Freights. - Unit operating costs for every production unit, from consumed amount and price of each utility. - Prices of product additives.
Output Data Economic	- Profit before fixed costs at optimum. - Various marginal changes of profit.
Production	- Optimal production strategy including rate of production for each product, blending recipes, feed rates of each production unit, run characteristics and severities of each unit. - Optimal investment strategy including type, capacity and probable characteristics of new production unit. - Optimal quality strategy within product specifications. - Utility requirements including potential self-production of utilities.
Marketing	- Optimal import and export strategy, including type and quantity of each product and raw material. - Optimal strategy for transporting to the consumers.
Observations	These models have proved to be of great assistance in decision-making in both the long and short term at the highest company level. Their use in various fields of company activity is steadily growing.

Summary supplied by the authors of the model.

FRANCE

The Model		J.P. Charpentier, G. Naudet, R. Paillot, 1973 (16), Commissariat à l'Energie Atomique, Paris. PANACH, Simulation Model of the Nuclear Fuel Cycle.
Subject and Goal		The goal of the model is to estimate the annual and cumulative amounts of different types of nuclear fuels needed by a set of various nuclear reactors. This set is the result of some assumptions of possible scenarios describing the development of electro-nuclear plants.
System Described		The model describes in great detail the network of the nuclear fuel cycle. Each step is considered: mining - milling - enrichment - manufacture - reprocessing and management of fuels inside nuclear reactors. This model could be used for both management and investment simulations.
Area	Time	From 1973 to the year 2000.
	Space	France as a whole.
Modelling Techniques		The flow of each nuclear fuel is followed through the overall nuclear network month by month.
Input Data		Only the physical aspect of the simulation has been implemented; investigation of the investments forecast and management cost are not yet ready. The number of input data is quite large, comprising detailed information (month by month) on: - the total electricity demand forecast that will be satisfied by nuclear plants - the scenarios describing what kind of nuclear reactor will be available (development of the breeder can be limited by the availability of plutonium, for example) - the volume of each kind of fuel used by each type of reactor - the exact timing between two successive operations in the fuel cycle.
Output Data		The main outputs are: - description of the nuclear investment programs that were included under certain conditions, e.g. the possible program of fast breeder reactors if their development were contingent on the availability of plutonium - evolution of the requirements of each kind of fuel at each step of the fuel cycle; the requirements can be supplied either month by month (or year by year) or in a cumulative form.
Observations		This model is still under development and incorporates the economic point of view (cost of investments and management).

Summary written by one of the authors of the model.

FRANCE

The Model		J.C. Dodu, 1970(17), Electricité de France, Paris. MEXICO, Electrical Network Transport.
Subject and Goal		Estimate of distribution safety (through a criterion of failure) in a large network.
System Described		Electrical network transport: emphasis on safety problems.
Area	Time	Static model for a particular point in time.
	Space	France as a whole - 100 nodes - network.
Modelling Techniques		The Mexico model uses sequential random drawing, adding thousands of situations where the electrical lines and the power plants are randomly available. The model minimizes the overall failure in each situation using a linear programming method. It also calculates shadow prices. Two minutes are necessary to investigate 2000 situations.
Input Data Physical		Each arc of the network is characterized by a proability of failure and a limit of capacity. Each plant is linked to a node and interferes with safety through its rate of failure. The consumption is given for each node.
Economic		Cost of failure.
Output Data Physical		The load-sheddings implemented to respect the constraints of the network and to minimize global failure provide the average failure. The 10 most troublesome cases are listed with relevant details in order to analyze them.
Economic		The shadow prices permit evaluation of the influence of the following factors upon global safety: - the limit of capacity of each line - the location of the thermal plants - the demand belonging to each node.
Observations		The Mexico model gives a global view of the weakness of the network: it takes into consideration the safety criterion which is essential for the planning of the network.

Summary supplied (in French) by the author of the model.

FRANCE

The Model		J.C. Duperrin and M. Godet, 1974 (18), Commissariat à l'Energie Atomique, Paris. MIC-MAC, Hierarchical Organization of the Elements of a System.
Subject and Goal		The general goal is to investigate the relative impact of different parameters - social, technical, economic or ecological - on the growth of nuclear energy.
System Described		In the preliminary qualitative approach, the relevant system of nuclear energy is described by a list of events or variables and by a set of qualitative relationships between these variables. The quantitative approach deals with the probabilities of the events.
Area	Time	In this model one must choose a reference (2000 in the application).
	Space	France as a whole.
Modelling Techniques		The qualitative approach consists of reducing the complexity of the studied system by selecting the most important factors. The set of variables and the binary relationships form a network. The criterion of importance considered for the hierarchization is the number of feedback loops intersecting a given factor. The quantitative approach is based on a cross impacts matrix. A linear program gives a set of probabilities for the "states of nature" (if the a priori probabilities of events provided by the experts are not inconsistent).
Input Data		Qualitative stage: a list of N variables and the matrix of the binary relationships between these variables. Quantitative stage: the N probabilities of the "isolated events" considered on a given time horizon; the N(N - 1) conditional probabilities of isolated events combined two by two.
Output Data		Qualitative stage: the hierarchy of factors (events) is given by the Mic-Mac program. Quantitative stage: a posteriori probabilities derived from the experts' estimates; probabilities of states of nature allowing the building of scenarios.
Observations		There are practical limits to the number of events to enter in the cross impacts model, because for N events the experts have to answer about $2 N^2 - N$ questions.

Summary reviewed by the authors of the model.

FRANCE

The Model		A. Breton, 1972[19]; D. Levi and D. Saumon, 1973[20], Electricité de France, Paris. Choice of Production Investments at E.D.F.
Subject and Goal		This model of long-term investments aims to determine the quantities of the different types of equipment (nuclear, thermal, classical, power pumping plants) to be put into operation every year.
System Described		System of electricity production without a transport network.
Area	Time	Dynamic model (area: year 2000).
	Space	France as a whole; punctual model without network.
Modelling Techniques		Optimization model using optimal control. The evaluation function is a function of cost consisting of three terms (investments, management, breakdown). Constraints for satisfaction of the demand and physical limitation (enforced or limited development of certain equipment). The algorithm operates in two steps: the control variables are established (quantities of equipment) and the optimal management at a fixed power of the entire electricity plant is then found. This problem is treated as a linear program, the solution of which is found by iteration on the marginal cost of the energy accumulated by the pumping plants. A new control is then deduced, which improves the expected value of the investment and working costs.
Input data Physical		The supply of the thermal and nuclear production of the entire electricity plant is considered on an average: each type of equipment is distinguished by an unavailability coefficient, the dispersion of which is neglected. The hydraulic production is shown in an aggregate manner (another model is used in order to allow the aggregation of the lake lockage work plants with the stream, taking into account the influence between plants). The production is random and the samples are provided from past hydrological data. The demand is indicated by "monotones" of weekly costs (calculated by a vectorial forecasting model from the levels of consumption by use and the appropriate characteristics for each one). The number of hourly positions varies (10 to 15). The level of annual consumption is contingent: 15 consumption drafts.
Economic		The cost of failure is an increasing function of the severity of the failure. The investment and fuel cost.
Output Data Physical		- Optimal equipment program. - Expected value of the economic life of this equipment. - Probability of failure.
Economic		- Marginal costs of production of different hourly positions. - Value in use of the equipment.
Observations		The model is used to generate the system of valorization which permits the estimate of profitability of individual projects (cf. "Use of global models for the choice of the program operation at E.D.F.;" Albert and P. Larivaille, Conference IFORS, Athens, 1968).

Summary provided (in French) by the author of the model.

F.R.G.

The Model		R. Bieselt, 1972[21], Technische Hochschule, Aachen. Development of Power Plants in Nordrhein-Westfalen.
Subject and Goal		It is the aim of the model to establish the optimal strategy for extension and operation of an electric power generating system over a medium-range planning period, minimizing net discounted costs over that period.
System Described		The power facilities are enlarged step by step, i.e. by adding individual power units. This procedure allows for the optimization of use on the basis of typical daily load diagrams. The intention is to arrive at a load distribution on the individual units which results in minimum fuel consumption costs. The model considers reserve capacity, maintenance and failure of power plants. Independent variables of the model are: - operational characteristics for each unit for different loads - discrete capacities for each type of unit.
Area	Time	Because of the discrete addition of power units only a medium-range planning period of 5 to 15 years can be used.
	Space	Can be generally applied; the only limitation to the number of the power plants under consideration is the computer time increase.
Modelling Techniques		The discrete independent variables (optimization values) are determined by means of either the modified branch and bound method or a modified dynamic programming routine.
Input Data		- The specific variable costs of the units installed at the beginning of the planning period as a function of the output of the unit. - The specific variable costs and installation costs for all units to be added. - Annual expected maintenance, repair and personnel costs of units to be added. - Characteristic daily load curves of working days, Saturdays, Sundays, in the form of discrete values for output/hr for each period of the year. - Budget data: interest rate, tax rate, depreciation period, insurance rate. - Calorific values and prices of fuels.
Output Data		- Energy distribution and load distribution for the individual power units in each period and in each year of the planning period. - Distribution of installed energy capacity and energy generation by type of power plant. - Utilization of the capacity installed. - Minimum cost sequence of the installation of new power units and the resulting overall costs.
Observations		The model has been used for investigations into the medium-term extension of the power system of Nordrhein-Westfalen (FRG). In addition to a full optimization run to sequence all new units, the user may prespecify some or all of the installation sequence. The stepwise capacity increase in principle allows consideration of questions of location and transmission system expansion. At present, studies are under way to incorporate these aspects.

Summary not reviewed by the author of the model.

F.R.G.

The Model		W. Meier and A. Voss, 1972[(22)], Kernforschungsanlage Jülich. RESTRAPRO, Reactor Strategy Program.
Subject and Goal		The model is meant to aid decision-makers in planning a long-term extension of electricity supply. It determines the optimum capacity distribution of different types of power plants in a power system, taking into account changes of load and other restrictions.
System Described		The objective function for the optimum extension of the power system is the minimization of the total system costs. It is assumed that for the period considered the total annual output of the electric supply grid is known. The load demands are described by a preset annual duration curve which for the purpose of linearizing the optimization problem is subdivided into constant load areas. Optimization takes into account side effects such as the condition that a power plant is removed from the reactor system only after the end of its life span, or that the amount of fissile material supplied by breeders is finite. The model consists of a first part, mainly the cost program for establishing electricity production costs dependent on load and time, and a second part, the optimization program.
Area	Time	The time horizon is not fixed. The model is better suited for long-term investigations.
	Space	Applicable to any larger power system.
Modelling Techniques		For optimization a linear programming statement is formulated and solved by the simplex method. Both a short-term (stepwise in time) and an integral optimization over the entire period of investigation investigation are possible.
Input Data		- Specific cost data of individual types of power plant; in the case of nuclear reactors also fuel charge and discharge vectors. - General budgetary data (interest and tax rates, depreciation period, etc.). - Annual duration curve. - Forecast bottleneck capacity.
Output Data		- Actualized costs of the reference system for each step in time of the investigation period: - Electricity costs - Installed capacity and expansion rate of each type of power plant - Energy production of each type of power plant of the overall system - Uranium and thorium consumption - Amounts of fissile material produced - Demand for separative work.
Observations		The expansion of power plants is typewise and not blockwise. The interactions between reactor expansion and grid extension are not considered, nor is the impact on the environment.

Summary not reviewed by the authors of the model.

F.R.G.

The Model	G. Meurin, 1972[23], Technische Hochschule, Aachen. Long-Range Expansion of a Power System.
Subject and Goal	This model is meant to support decision-makers in the optimum planning of a long-range expansion and operation of a power system in a closed economic region. For a planning period of several decades, the cash value of integral electricity production costs as a function of the distribution of capacity expansion and energy production of several power plant types was established.
System Described	The model describes the electricity supply of a closed economic region, not taking into account the supply grid. The cost-optimum supply of electricity is determined on the basis of the existing power plant system, a forecast of future electricity demand, and a forecast of changes in load distribution. The four power plant types discussed are: - Traditional thermal reactors - Nuclear power reactors - Hydro-electric power plants (natural inflow) - Pumped-storage plants. For consideration of load distribution, diagrams of annual electricity production are used which are based on typical daily production curves. The problems of reactor shut-down, reserve capacity and power plant output are also discussed.
Area – Time	The model is applicable to any desired period of investigation of several decades, whose upper range in principle is limited only by the storage capacity of the computer.
Area – Space	In principle the model is applicable to any closed economic region.
Modelling Techniques	To solve the minimization problem, the model uses a method of non-linear optimization in which the minimization problem that is not fully convex is solved by means of iteration.
Input Data	- Data on the structure of the power plant at the beginning of the planning period. - Forecast of the development of annual electricity consumption. - Preset annual production diagrams. - Economic and technological characteristics of individual plant types. - General economic data such as interest rate, tax, depreciation period.
Output Data	- Time distribution of capacity and of the energy production of individual power plant types. - Overall costs within the planning period. - Annual and cumulative demand for natural uranium and other fuels. - Demand for separative work and for reprocessing. - Amounts of fissile material produced.
Observations	Power system expansion calculations for the F.R.G. have been made by using this model; the planning period altogether was 30 years, each stage covering five years. The expansion of the electricity transmission and distribution grid and environmental aspects were not considered.

Summary not reviewed by the authors of the model.

F.R.G.

The Model		H. Tröscher, 1973 (24), Rheinisch-Westfälische Elektrizitätswerke AG, Essen. Electricity Utility Model.
Subject and Goal		The aim was to develop a model system for the expansion planning of an electrical supply facility, of use for the integrated planning of electricity generation, transmission system expansion and financing.
System Described		The expansion planning of an electrical supply facility is described by five sub-models for: - Forecasts of demand and earnings - Planning of generation expansion - Planning of power station scheduling - Planning of transmission system expansion - Profit and loss accounting, balance sheet preparation and financial planning. With the model system it is possible to simulate the effect of interdependence and to use an iterative solution process (simultaneous determination is not possible) to find quasi-optimum solutions for generating expansion, transmission system expansion and financing.
Area	Time	A planning horizon which extends to the next 20 years.
	Space	The model was developed for the area of an electrical supply facility (Rheinisch-Westfälische Elektrizitätswerke AG, Essen).
Modelling Techniques		The market model calculates the medium- and long-term forecast of energy demand, load demand, load characteristics and receipts from energy sales by using regression and correlation analysis methods. A dynamic programming method is used to determine the expansion sequence for the generation units, taking into account the load and operating characteristics and reliability criteria for energy production. Trial and error methods of sub-optimization and simulation are used for system expansion planning. A deterministic simulation method is used in the finance model to simulate the rules describing the financial behavior of the electric utility.
Input Data		The main input data are: - Past data of energy demand, load demand and load characteristics and their indicators, such as GNP, prices of competing energy sources, temperature patterns, etc. - Technical and cost data of the different power plants and the grid expansion - Economic data, such as taxes, depreciation, repayment of loans and credits, interest due on loan capital, fixed assets, etc.
Output Data		The main output data are: - Demand and earnings forecasts - Expansion strategies for the power plant and transmission system - Financial requirements - Security of supply - On-time determination of revenue and expenditure and inflow and outflow of financial resources.
Observations		The model does not take into account environmental problems. It does not permit simultaneous determination of integrated plans for generation expansion, transmission expansion and financing.

Summary not reviewed by the author of the model.

JAPAN

The Model		Institute of Energy Economics, Tokyo, 1973 [25]. Growth of Nuclear Power.
Subject and Goal		This model aims at estimating future nuclear power capacity in the national power system and optimizing nuclear reactor strategies. From the results, the characteristics of the nuclear fuel cycle and the investment demanded for each fuel cycle component can be calculated.
System Described		The system is divided into three sub-systems: - calculation of load duration curve - optimization of annual incremental capacity and replacement between 6 types of plant (3 thermal and 3 nuclear power reactor) - calculation of the nuclear fuel cycle.
Area	Time	30 years.
	Space	Japan as a whole.
Modelling Techniques		The load duration curve is presented as a complex exponential and trigonometrical function. The optimum composition of the power source is determined by the relative competitiveness among 3 types of thermal plant and 3 types of nuclear reactor, minimizing the total generating cost of the volume of power generated at each source. In the case of the power reactor, the distribution of thermal and fast reactors is affected by Pu-balance in each year.
Input Data		Annual incremental and replacement capacity in each year; capital and fuel cost of each power source; design parameters of each reactor type.
Output Data		Composition of the power source and its accumulated capacity in each year; generating cost of each power source and system power cost; amount of fuel at each step of its cycle, and the corresponding investment.
Observations		The main parameters necessary to examine reactor strategies are integrated in this model. The model can be used to estimate cost competition among the various types of power source.

Summary supplied by the author of the model.

POLAND

The Model		Marek Bernatowicz, 1974[26], Institute of Nuclear Research, Swierk near Otwock. Nuclear Power System Optimization.
Subject and Goal		To find the optimal composition of a multicomponent nuclear power system at the initial period of its development. The load factor of particular power plant types is assumed to be constant in this period; by this assumption the model is linear.
System Described		The total number and size of nuclear power plants to be constructed in the period considered are given (total number of plants = r, number of types of plants considered = m). Each of r plants must become a plant of an m-allowed type ("plant number balance"). No exchange of plutonium between the system and the rest of the world is allowed. Thus the construction of plutonium-fuelled reactor plants is limited by the plutonium balance constraints. The possibility of plutonium fuelling of thermal reactor plants previously started with uranium as fuel is allowed. A thermal reactor plant can be switched to plutonium fuelling only if the special pseudotype constraints and the plutonium balance constraints are satisfied.
Area	Time	The constant load factor condition can be met during the first 20-25 years in some countries.
	Space	--
Modelling Techniques		Optimization model based on the branch-and-bound technique with linear programming for determination of the bounds for each branch and for selection of the separation variable. The objective function corresponds to the total electricity generation cost. Three kinds of constraints have to be satisfied: plant number balance, plutonium balance, and pseudotype constraints.
Input Data Physical		- Plutonium production and consumption rates for each nuclear power plant type considered. - Initial plutonium inventory of reactor power plant started with plutonium as fuel. - Load factors for each of plant types. - Number of nuclear power plants to be constructed in each year of the period considered.
Economic		Yearly capital costs and variable costs for each plant type considered.
Output Data Physical		Type of plant to be constructed in the period considered, in order to design an optimal system.
Economic		Total electricity generation costs (optimal value).
Observations		This model can be used only if the required plant number for each year can be specified and if the load factor constancy assumption is observed.

Summary supplied by the author of the model.

POLAND

The Model		Jan Podpora, 1974[27], Institute of Nuclear Research, Swierk near Otwock. System of Two-Component Nuclear Power.
Subject and Goal		Analysis of a nuclear power system from the point of view of fuel balance and fuel management.
System Described		A two-component system consisting of fast converter reactors (FCR) and fast breeder reactors (FBR), or alternatively of thermal reactors fuelled with uranium and FBR.
Area	Time	Area of interest: initial period of development of the system.
	Space	--
Modelling Techniques		On the basis of the plutonium balance the division of capacity between the reactors fuelled with uranium and plutonium is found. The routine allows one to input data on the loading and unloading of the fuel from the reactors in the form of discrete batches distributed in time, and thus permits investigation of the influence of various refuelling schemes and time delays in the fuel cycle on the fuel balance of the system.
Input Data Physical		- Nuclear power demand in sequential years of the period considered. - Distribution in time of the fuel loading and unloading batches during the life of the reactor; these values for the FCR and FBR can be computed using another routine elaborated by the author.
Output Data Physical		- Capacity installed in reactors fuelled with uranium and plutonium. - Uranium demand in sequential years of the period considered. - Reprocessing plant capacity required.
Observations		The model can be used for accurate analysis of the dynamics of a two-component nuclear power system containing fast reactors, both plutonium and uranium fuelled. It allows one to assess the inaccuracy of simpler models commonly in use.

Summary supplied by the author of the model.

POLAND

The Model		Waclaw Frankowski, 1970[28], Institute of Nuclear Research, Swierk near Otwock. Power Plant System with Variable Load Factors.
Subject and Goal		To find the optimal structure of a developing electricity generating system composed of various types of thermal and fast reactor nuclear power plants and some conventional power plants. The load factor of each type in an optimal system changes in time and depends on its share in the total capacity at a given moment and its position in the load demand curve.
System Described		Given the total capacity of an electricity generating system in subsequent years up to some horizon, the system is to be optimal from the point of view of the total energy production cost. It is autarchic in that no exchange of plutonium between the system and the rest of the world occurs. Hence, the share of the fast reactor plants is limited by the plutonium balance constraints. The future development of the system is strongly influenced by its history, i.e. the pattern of its development before the installation of the first nuclear power plant. The optimization covers the period between installation of the first nuclear power plant and the time horizon. The load factor of all power plant types allowed is not preset but is an implicit variable of the optimization process for the whole period investigated (see section above). Thus a function representing the load demand curve is included in the model. Its introduction makes the problem a nonlinear one.
Area	Time	25 years or more depending on the numerical possibilities.
	Space	--
Modelling Techniques		Nonlinear optimization model solved using the LAP (linear approximation programming) technique. The total energy production cost during the period investigated is to be minimized. Optimization is done under constraints of total capacity, plutonium balance, and the past of the system.
Input Data Physical		- Plutonium production and consumption rates of a set of nuclear power plant types (both thermal and fast reactor). - Initial plutonium inventory of fast reactor power plants. - The function representing the load demand curve of the system. - The set of "the past of the system" data. - The set of values denoting the annual capacity growth of the system as a whole.
Economic		Yearly capital costs and variable costs for all of power plant types allowed.
Output Data Physical		The values of the capacity newly installed in each type of power plant each year from first installation of a nuclear power plant to time horizon, for the optimal case. These values are assumed to be the continuously variable independent variables of the problem.
Economic		Total energy production cost.
Observations		- The problem becomes very difficult for effective numerical solution with increasing length of the period investigated and the amount of power plant types allowed. - The discrete character of capacity installation (units of say 500, 1000, etc. MW) is not taken into account.

POLAND

The Model		Waclaw Frankowski, 1969 (29), Institute of Nuclear Research, Swierk near Otwock. Power Plant System Development .
Subject and Goal		Find the optimal structure of a developing system of nuclear power plants composed of various types of thermal and fast reactor plants. The load factor of a given type is assumed to be independent of its power share in the total power of the system. This condition is fulfilled when the capacity of the system does not exceed 25-30% of the total capacity of the electricity generating system (the initial stage of development of its nuclear component).
System Described		Given the total capacity of a nuclear system in subsequent years up to some horizon, the system is to be optimal from the point of view of the total energy production cost. It is autarchic in that no exchange of plutonium between the system and the rest of the world occurs. The share of the fast reactor plants is thus limited by the plutonium balance constraints. Plutonium fuelling of thermal reactor plants previously started as uranium fuelled ones is allowed. The capacity switched to plutonium fuelling is limited by the pseudotype share constraints. Fast reactor plants always remain plutonium fuelled.
Area	Time	The constant load factor condition can be met during the first 20-25 years in some countries
	Space	--
Modelling Techniques		Optimization model using linear programming. The criterion of total energy production cost is formulated in two variants: the total cost to the time horizon, and the total cost to the end of life of power plants built up to the end of the interval "zero-time horizon." Optimization is done under constraints of total capacity, plutonium balance and pseudotype share.
Input Data Physical		- Plutonium production and consumption rates of a set of nuclear power plant types (both thermal and fast reactor). - Initial plutonium inventory of a set of fast reactor power plant types. - The set of load factors for particular power plant types. - The set of values denoting the annual capacity growth of the system as a whole.
Economic		Yearly capital costs and variable costs for all of power plant types in question.
Output Data Physical		The values of the capacity newly installed in each type of power plant in subsequent years of the interval "zero-time horizon," for the optimal case. These values are assumed to be coninuously variable.
Economic		Total energy production costs in both variants (see Modelling Techniques).
Observations		The discrete character of capacity installation (units of say 500, 100 etc. MW) is not taken into account; this has been shown to have little influence on the results in many cases of interest.

Summary supplied by the author of the model.

SWEDEN

The Model	Göram Bergendahl, 1974[30], University of Gothenburg. Multi-Period Cost Minimization Model for Sweden.
Subject and Goal	The aim of the model is the determination of the Swedish electricity power system such as to meet demand by a production at lowest cost. The model gives only a very simplified projection of the electricity power system so that it is impossible to describe a detailed energy policy.
System Described	The investments in the power system are scheduled up to 1976. The first year will therefore be 1977; it is assumed that all investments are introduced each fifth year only. The average demand is assumed constant in the 5 year periods. The investment schedule for hydro-power plants is given. The other plant types are: - Nuclear power plants - Peak-load fossil plants - Base-load fossil plants - Gas turbines. The demand flexibility is given by a piecewise linear approximation of the value of consumer advantages, defining the benefits as a function of demand. The load duration curve is reduced to fixed demand in 5 time segements.
Area — Time	The years of interest are 1977, 1982, 1987, etc.
Area — Space	The electricity power system of Sweden.
Modelling Techniques	Using linear programming the model finds the solution minimizing the total discounted costs over the 3 periods for a given demand. Six kinds of constraints constitute the set of feasible solutions for investment, capacity and electricity supply. The costs to be minimized are: - The cost of producing 1 unit of energy (kWh) (per plant type, time segment and time period) - The cost of operating (and maintaining) 1 unit of power (kW) (per plant type during 1 time period) - The cost of investment in 1 unit of power (kW) for 1 plant type to be available at the beginning of the time period. The constraints that must be satisfied are: - Demand per time segment less than the production at all power plants per time segment - Production per time segment less than the total amount of available capacity (product of maximum number of hours of operation and capacity by time segment) - Product of reserve capacity factor (policy parameter) and the production in all power plants per time segement less than total amount of available capacity - Restrictions which guarantee an even production rate for nuclear and base-load fossil-fueled plants only - Total annual amount of energy produced at hydro-plants less than the upper bound of hydroproduction - Production in kWh during the summer interval greater than the minimum production caused by non-variable water power.
Input Data	- Power production as scheduled for 1977. - Given investment schedule for hydro-plants. - Estimated demand per time segement or the consumers' values (per kWh) of changing consumption from the projected demand. - Availability of production per time segement and plant type. - Minimum hydro-production for summer-time segments and for the different time periods. - Cost of production, operation and investment in different types of plant.
Output Data	- Nameplate capacities (in MW for different plants and time periods) (investment is simply the difference between capacities in each year). - Energy production (in TWh) for each time segment of a year and each time period for the 5 plant types. - Capacity utilization in percentage of available capacity during each time segment. - Wholesale prices set to marginal costs of producing 1 additional unit of energy (given as Sw. Crs./kWh).
Observations	The model takes no account of size and location problems of each plant. The demand flexibility is determined only by the price, not by factors such as convenience, reliability, safety, environmental effects.

Summary not reviewed by the author of the model.

SWEDEN

The Model		E.S. Ben Salem and M. Höjeberg, 1973 (31), Government Committee for Energy Forecasting, Stockholm. Energy Supply and Demand Forecast.
Subject and Goal		To investigate the sensitivity of the Swedish energy system to changes in parameters, e.g. price of oil, technology for energy conversion.
System Described		The model allows substitution between different kinds of primary energy in the production of secondary energy; between energy and other input factors in house heating; and between more or less energy-consuming final commodities. In addition, the model estimates the amount of several pollutants produced by the energy sector.
Area	Time	A static model solved for a number of years with a 5 year interval between each year. The model is not solved for years later than 2000.
	Space	Sweden.
Modelling Techniques		The model has a general equilibrium framework. The supply of secondary energy and the demand for energy for house-heating are determined by means of a linear activity model while industrial demand for energy is determined in a model similar to Leif Johansen's "Multi-Sectoral Growth Model." First the supply and demand parts of the system are patially solved; later a general solution to the whole model is investigated.
Input Data		
Physical		The description of power stations, refineries and house-heating systems is based upon engineering data; somewhat revised official input-output data are utilized for the rest of the model.
Ecological		Emissions of different kinds of pollutants from power stations and refineries are specified as linear functions of the activity level in the processes in question.
Economic		In the partial solutions, the inputs, except primary energy, are valued in 1971 prices. In the general solution all prices (except of energy resources) are endogenous. To close the system, different assumed price paths for primary energy are used.
Output Data		
Physical		The model determines Sweden's future use of energy resources subject to the prices of energy resources, the energy policy and technological change in the energy supply sector.
Ecological		A vector of emissions to the environment is associated with each solution. Alternatively the solutions can be constrained by different environmental standards.
Economic		The model determines a path of equilibrium energy prices.
Observations		It is planned to complete the model in summer 1975.

Summary supplied by the author of the model.

TURKEY

The Model		Dennis Anderson, 1972 (32), International Bank for Reconstruction and Development. Models for Determining Least-Cost Investments in Electricity Supply.
Subject and Goal		Optimal investment and operation schedule for long-term planning of Turkish electricity supply system.
Area	Time	Covers 25-35 years. Applied to the Turkish system between 1975 and 2010.
	Space	Turkey as a whole.
Modelling Techniques		Linear programming. The objective function is the present worth of capital and operation costs of different plant types. Seven different constraints deal with energy capacity and demand relations. Results are obtained in lumped quantities in chosen periods on the time horizon.
Input Data Physical		Type of available resources from which plants may be developed, maximum capacity of resources, load factors of plants, time horizon and period demands, availability of plants, linearized load duration curves of periods, allowed hydro/thermal ratio of the system. The number of resource types and of periods, and the degree of sophistication of the load duration curve, are limited only by the size of the computer available.
Economic		Capital cost per unit power, operational costs per unit energy, and data relevant to the economics of scale.
Output Data Physical		Amount required from each type of resource and operation schedule for each selected period of time.
Economic		Total minimized cost and marginal quantities for some variables.
Observations		The model cannot be used for short-term planning. Social and political decisions may be represented to some extent by using upper or lower bounds on variables. It can easily be extended to include seasonal variations, network constraints and replacement, depending on computer size.

Summary supplied by the author of the model.

U.K.

The Model		C.E. Iliffe, 1973[33], U.K.A.E.A., Risley, Warrington, Lancs. Simulation of a Nuclear Generating System.
Subject and Goal		The model has been developed mainly for assessing the economic benefit of introducing alternative types of nuclear station into the UK power program as an aid in formulating development policy. It is possible to regard the variation in the load factor throughout the life of each station. This analysis can also take into account any rise in the price of uranium ore and fossil fuel, and the fall in capital costs through replication and in fabrication costs of nuclear fuel as plant throughputs increase. The model was coded for the computer in FORTRAN; the current version is called DISCOUNT-G.
System Described		The model is applied to a typical representation of the UK generating system including both fast and thermal nuclear stations. The nuclear power plants are subdivided into various types and classes.
Area	Time	Instants of time are measured from 1 to 200 and correlated with a calendar year as a base date; each corresponds to the start of a calendar year, or, in the case of half-year intervals, to the middle of a year.
	Space	The electricity generating system of the United Kingdom.
Modelling Techniques		Unlike a linear programming model the DISCOUNT code requires a prediction of the split between nuclear and fossil fueled plants to be included. By applications of the model with variation in the plant mix, guidance can be obtained as to its most favorable values. The economic criterion is the present worth of the expenditure on the system. The only automatic adjustment of the mix is that required to balance plutonium supply and demand. The station generating costs are subdivided into the components: - Construction costs of the station and outlay on its intial fuel charge - Value of the fuel in the reactor at the time of shut-down, and residual value at the station - Operating cost - Replacement cost (loss in value of the fuel per unit of electricity generated) - Value of the fuel stocks held on the station site. The demand duration curve is obtained by subdividing the year into equal fractions or seasons.
Input Data		A lot of input data are necessary; the main ones are the following: - Total generating capacity, measured in terms of stations and given as a function of time - The Commissioning limits (upper or minimum) to the number of FR stations - The annual mean availability of stations (AGR and HTR, Magnox, FR) - The merit order of plant types - The annual mean-duration more as a function of time - The plutonium production rate quoted as a function of the station operating time.
Output Data		The main output data are the following: - Total stations installed - The number per type of station - The costs - The cash flow.
Observations		The DISCOUNT code has been in continuous use in the UK for the economic assessment of possible development in nuclear power. Improvements will be made, particularly in the optimizations of station mix.

Summary not reviewed by the author of the model.

U.K.

The Model		F.P. Jenkin, 1973 [34], Central Electricity Generating Board, London. Electricity Supply Model
Subject and Goal		This model was developed to evaluate long run generation plant mix in an all-thermal system to give simple solutions suitable as a basis for assessing future development. It can be used for background planning over a certain time period to give the optimal plant mix.
System Described		The model describes the electricity supply system of the CEGB (Central Electricity Generating Board) in Great Britain. The planned available electricity generation is taken as equal to the peak demand. For the calculation of operating costs the load duration curve in each year of the background period is taken.
Area	Time	The model determines plant increase curves of each plant type over a chosen background time.
	Space	The public electricity demand in England and Wales supplied by the CEGB.
Modelling Techniques		A continuous function model; the equations of the supply curves which minimize the objective function are given by the calculus variation. The objective function includes the capital and operating costs. The introduction of random variables for capital and operating costs allows the application of probability theory to deal with the problem of uncertainty. The annuity charges of effective capital cost (capital cost of installed plant divided by availability at peak) and the increase in plant determine the capital cost of the objective function. The total operating cost function is determined by the load duration curve and the operating cost per KW. For the boundary conditions of the problem, the optimality equations are either in Du Bois Reymond's equation or, if differential with respect to the time, in Euler's equation. The boundary conditions are: the supply of each plant is fixed at t = 0 and the objective function is 0 at t = T (T: end of background period).
Input Data		- Deterministic or probabilistic values of costs. - Load duration curve. - Peak demand curve.
Output Data		The increasing capacity curve for each plant.
Observations		This model gives only a simple solution suitable for use as a basis for assessing future development of the power generating system.

Summary not reviewed by the author of the model.

U.S.A.

The Model		H. Houthakker and M. Kennedy, 1974[35], Harvard University, Cambridge, Mass. Energy Demand as a Function of Price.
Subject and Goal		Estimating the demand for certain energy sources as a function of income, price and past quantities of demand. This model tries to find an adequate analysis of the response of consumers to price.
System Described		This dynamic flow-adjustment model could be applied to different cross-sections of states over different time intervals and for different kinds of fuels. Up to now, the model has been applied to the U.S. and OECD countries for electricity and different kinds of distillate fuel oil.
Area	Time	For middle- and short-term forecasting (7 - 10 years).
	Space	For only one kind of fuel in one country.
Modelling Technqiues		Multiple linear regression. At each time the logarithm of the quantities of demand appears as a linear function of the logarithms of income, price and quantities of consumption in the preceding period. This result comes from two assumptions: - In the long run, the desired level of the demand for one year is a log-linear function of income and price. - The actual relative growth of the demand is a linear function of two factors: the relative growth of the desired demand and the relative growth of consumption in the preceding period. Elimination of the desired demand from the two equations generates the equation representing the real demand as a function of price, income and past trend.
Input Data		For each country and each kind of fuel studied, past data trends (on approximately ten years) are needed, namely: - The volume of consumption - The prices of the fuels studied (at a constant price, i.e. deflated price) - The income of the consumers (at a constant price).
Output Data		The main output data are: - The short- and long-run price elasticity - The short- and long-run income elasticity.
Observations		The coefficients of correlation from the different regressions are very good. This model has also been developed by the authors a sub-model of the world oil market (cf. p. 46).

Summary not reviewed by the authors of the model.

U.S.A.

The Model	P.W. MacAvoy and R.S. Pyndick, 1973 (36), Massachusetts Institute of Technology, Cambridge, Mass. Policies for Dealing with the Natural Gas Shortage.
Subject and Goal	If the demand for gas grows as expected during the 1970's and if ceiling prices remain as low as over the past decade, the shortage in natural gas production could grow significantly. This paper examines the effects of existing and alternative regulatory policies for gas reserves, production supply, production demand, and prices over the remainder of this decade.
System Described	The model treats simultaneously: - The field markets for reserves: gas producers guaranteeing delivery of new reserves to pipeline companies at the wellhead price - The wholesale markets for production: pipeline companies selling gas to retail utilities and industrial consumers. In surveying the interaction of these two sets of markets, their behavior has been considered in the rather complex case when there is considerable excess demand for production.
Area — Time	1966 - 1980.
Area — Space	USA as a whole.
Modelling Techniques	The model consists of a set of almost all simultaneous linear econometric relationships among several policy-related variables. For the various field and wholesale markets, endogenous and exogenous variables are considered. Field reserve and production equations are estimated for the supply regions. Wholesale demand equations are estimated for each of 5 parts of the country. The model is then used to evaluate 3 policy alternatives. A simulation of the model has been performed over the period 1965 - 1971.
Input Data	The model is estimated using pooled cross-section and time-series data: Wholesale market - Income - Population level - Investment capital - Value added in manufacturing - Wholesale price of alternative fuels for residential, commercial and industrial use Field market - Wellhead price of oil and gas - Average price of fuel paid by electric power companies - Average drilling costs for oil and gas together - Distance from the center of a producing region to the center of the consumption region - Volumetric capacity of pipelines - Dummy variables for some regions.
Output Data	Field market - Non-associated and (oil) associated discoveries of gas reserves - Extensions and revisions of reserves - Well drilling Wholesale market - Demand for production of gas and wholesale prices for 3 wholesale delivery sectors: mainline industrial sales; sales for resale, either for industrial or for residential and commercial use. - Supply of production and new contract field price - Simulated policy alternatives 1) Deregulation of wellhead prices of new reserves of natural gas 2) Strict "cost of service" regulation of new contract prices 3) Maintenance of the regulatory status quo which allows only a certain price increase on new contracts.
Observations	The authors deem the first and third alternatives preferable to strict "cost of service" regulation.

Summary not reviewed by the authors of the model.

U.S.A.

The Model		Alan S. Manne, 1974[37], Harvard University, Cambridge, Mass. Waiting for the Breeder.
Subject and Goal		This model aims at selecting an optimal mix of electricity generating plants, focusing on the problem of uncertainty in the availability date of breeder nuclear reactors. Sequential probabilistic linear programming is used. This makes it possible to optimize the mix of fossil, nuclear and peaking plants to be installed during the 1980's - assuming that breeder technology becomes available at some randomly determined later date. The model allows for the effects of exhausting our reserves of uranium ore.
System Described		The model describes the global electricity system as to demand and supply. The demand is considered either independently of the price (using estimates of a decelerating growth rate) or as a nonlinear function of the price. In the latter case, there is a five-step piecewise linear approximation. The relation between demand and the necessary capacity is described by a load-duration curve divided into three blocks: base-load, intermediate and peak-load. Some assessments on the evolution of fuel prices are made. The fossil fuel price forecast is based on an arithmetic annual growth rate. For uranium ore, the price depends nonlinearly upon the cumulative production, again using a piecewise linear approximation.
Area	Time	From 1985 to 2025 in 5 year steps for 9 time periods.
	Space	US electricity generating system as a whole.
Modelling Techniques		This is an optimization model using sequential linear programming. The objective function is the minimization of the expected present value of costs. The breeder-available date is viewed as a random variable with a subjective probability. It has been assumed that the breeder will become available either in 1995 or 2000, or not at all within the planning horizon period. In this constrained optimization model, the minimand denotes expected discounted costs. Note that this is the only point in the entire tableau where the probabilities p_s enter explicitly. In each constraint equation and variable, there is an index denoting the state-of-world: whether the fast breeder reactor will become a safe and competitive technology in 1995, 2000 or never. For each time period and state-of-world, there are equations for: - The demand requirement by blocks of the load curve - The capacity of utilization of each kind of plant - The annual fuel requirement for each kind of plant - The cumulative fuel requirements.
Input Data Physical		Supplies - The annual needs of each kind of plant (light water reactor, fast breeder, peak storage and 3 types of fossil units). - The performance factors and modes of operation of each plant. - The life-time of each plant (30 years).
Economic		Demands - The reference price and quantity of electricity. - The price elasticity factor (= - .5). Supplies - The discount factor (10% per year). - The cost of each fuel; the 1985 average fossil fuel cost is taken as $\$1.00/10^6$BTU, increasing at the rate of $\$.01/10^6$BTU. To allow for increases in uranium extraction costs as a function of cumulative production, there are 5 ore extraction cost categories. Optimization automatically ensures that each of the lower-cost resources will be exhausted before the next higher-cost ore is utilized. - The investment cost of each kind of plant (or the capital recovery factor). - Operating and maintenance costs.
Output Data Physical		The annual requirements of each kind of fuel (uranium ore or fossil fuel) according to each of the 3 availability dates of the breeders.
Economic		- The optimal installation and equipment utilization strategy for the system in each of the 3 cases: breeder available in 1985-2000-never. - The expected value of the supply system, incorporating subjective probabilities for the availability date of the breeder. - The marginal value of electric energy in each block of the load-duration curve.
Observations		For each time period and state-of-world, there is an optimal strategy for each of the unknowns: capacity increments of each kind of plant, modes of operation, demand levels and annual requirements for uranium ore. Altogether, there are 9 time periods and 1100 variables.

Summary reviewed by the author of the model.

U.S.A.

The Model		W.E. Mooz, 1973 (38), Rand Corporation, Santa Monica, California. California's Electrical Energy Demand.
Subject and Goal		The model has been built for the Resources Agency to help in preparing a 25 year power siting plan. It consists of a forecast of disaggregate electrical energy demand in California. Forecasting methods used so far by California utilities, are also discussed.
System Described		The following consumption sectors describe the demand system: residential, commercial, industrial, agricultural, governmental and miscellaneous. These sectors are subdivided into 5 geographical areas.
Area	Time	The model gives middle to long range projections; it covers the 1955-2000 period.
	Space	California, broken down into 5 areas.
Modelling Techniques		Econometric models - Each sector of the demand is studied separately. - The projections of the residential sector are based on the estimates of saturation growth curves of 28 electrical household appliances and on the evolution of their electrical characteristics. - The projections of the industrial sector are based on the concept of energy intensiveness (kWh per $ of added value), which combined with expected prices and size and structure of the industrial sector determines electrical demand. - The commercial sector is assumed to be driven by projections of the commercial share of Gross Sectoral Product (GSP), the electrical energy intensiveness of the commercial sector and energy prices. Each submodel includes long run price elasticities operating through lag coefficients.
Input Data Physical		- Population. - Energy intensiveness. - Technological change.
Economic		- Long run price elasticities. - Gross Sectoral Product (GSP).
Output Data		Sector demands for electrical energy.
Observations		Some further research is planned to obtain a better representation through disaggregation of the commercial and industrial sectors; more accurate elasticities; a restructurization of the data systems of the utilities.

Summary not reviewed by the author of the model.

U.S.S.R.

The Model	I.N. Bessonova, N.S. Kulenow, Z.H. Hasenov, S.C. Chokin, 1973 (39), G.M. Krzhizhanovsky State Research Institute of Energetics, Moscow. Energy Consumption Forecasting.
Subject and Goal	A method is proposed for forecasting industrial energy demand as a preliminary stage for using an optimization model of energy supply. Attention is drawn to the reliability of the forecasts, and improvements which can be made in the commonly used regression methods.
System Described	The forecasting method uses economic indicators, in particular the rate of production growth, essentially in the electricity sector. Another method is used for the other forms of energy. It is assumed that the power consumption forecast acts also as a control value in predicting industrial energy requirements as a whole.
Area – Time	Approximately 5-10 years.
Area – Space	USSR (and an application in Kazakhstan).
Modelling Techniques	To calculate the prospective level of power consumption in industry W_t, the following expression is used: $W_t = W_o \cdot I_t \cdot K_t$ where K_t is the index of electric power consumption per unit of production and I_t is the index of production growth. The calculation is made for successive 5-year periods, the W_t of the previous period being the initial level of power consumption W_o of each subsequent period. On the basis of a statistical aggregate of indices of production for 5-year periods and corresponding mean indices of electric power consumption per unit of production for 10 industrially developed countries, a generalized empirical relation has been established between K and I.
Input Data	K(5): index of electric power consumption per unit of production for 5-year periods. H(5): index of total fuel consumption growth for a 5-year period. I(5): index of production growth for a 5-year period. (The influence of temperature differences on the consumption curve can, to a great extent, be eliminated by the use of indices for 5-year periods). E_{io} : initial specific electric power consumption in industry i. K_{it} : specific power consumption in an industry i, depending on the production growth rate in this industry. S_{it} : prospective share of an industry in total volume of production.
Output Data	The relation between K and I is a' +b/I(5) where a and b are parameters. For fuel consumption, an example of the relation is: H(5) = a' + b/I(5). A more general model is also proposed which takes into account the actual power consumption per unit of production and the branch structure of industrial production, as well as their prospective changes. Thus, the general specific electric power consumption K_t can be expressed as a sum of its components in particular industries: $W_t = W_o \cdot I_t \cdot \sum_{i=1}^{n} E_{io} \; S_{it} \cdot K_{it}$
Observations	Other methods have been used for Kazakhstan: - paired correlation between electric power consumption and production growth, and between electricity consumption per worker and labor productivity. - multiple correlation with national income, GNP, basic funds, population, labor productivity, industrial production per capita, etc. The correlation coefficient of some factors was found to be sufficiently high (0.8). At the same time, a high correlation between input parameters precludes application of existing formal algorithms used for developing regression equations. Several methods have been used to avoid this correlation, in particular the method of main components. Introduction of 2 or 3 main components brings about convergence of the model with the real process (R = 0.99). The growth rates of industrial consumption of particular fuels are not only connected with rates of production growth, but depend on peculiarities of the power consumption structure. To adjust the independently obtained levels of electric power and fuel demand, it is expedient to calculate their prospective conversion ratio, i.e. power-and-fuel coefficient (kWh/tce). This index is characterized by a continuous increase in the rate (1% - 5% annual increment).

Summary not reviewed by the author of the model.

U.S.S.R.

The Model		A.I. Mekibel and T.M. Polyanskaya, 1973[40], Central Institute of Economics and Mathematics, Moscow. Power Industry Models.
Subject and Goal		Two separate models are presented for the petroleum industry and the coal industry, showing how the planning of the energy sector should be carried out. The related factors which link the various branches of the energy sector and the geographical regions, on the one hand, and the energy sector with the rest of the economy on the other, are briefly indicated.
System Described		These models are used for the long term planning of the evolution of the energy sector.
Area	Time	Planning in several phases, taking as a horizon 5, 20 or 30 years.
	Space	The USSR as a whole.
Modelling Techniques		Both models are optimization models using linear programming. Model for petroleum: the optimality criterion is the minimum integral cost of crude oil extraction, transportation, and distribution. The seasonal variation of demand is taken into account. We are thus induced to investigate the size of stocks and reserve production capacity of refineries. Model for coal: the objective function is the sum of total costs. The same model, with the possible introduction of a number of transformations, has two goals: - planning the production of each mine (increase in production capacity). - planning of the coal industry as a whole. The connection between the two types of planning is provided by the marginal costs. The links with the other energy branches are assured through the bias of coal demand, principally due to the substitutions which may take place in the form of natural gas or petrol.
Input Data		Model for petroleum: the model considers essentially the refining and distribution of petroleum products, with emphasis on the formalization of the refining process of the multi-product industry. Different equations describe: - the production of petroleum products from crude oil. - the consumption of crude oil and raw material necessary for refining. - the distribution of petroleum products to various districts. The input data are: - yield factor of the transformation of crude oil into gasoline, diesel oil, etc. - yield factor of straight distillation fractions for various processes. - consumption of raw material by refineries. Model for coal: this model considers the entire coal industry from extraction of coal to its transformation and distribution to consumers. Each mine is treated individually. The interchangeability of coals is represented by relative power efficiency coefficients. For the plants as a whole, equations for the balance of production and transformation of coal and demand are given. The input data are: - yield factors for various grades in processing of coal. - the demand for coal for each consumer. - the variables of the model indexed according to coal grades, mines, different kinds of processing and consumers, areas, time.
Output Data		Model for petroleum: - the quantities refined in existing plants. - the delivery of end products for consumption. Model for coal: the coal production for each value of the above-mentioned indices is recorded.
Observations		A number of procedures are used to determine the basic data for the two models. Several iterations were carried out for studying the suitability of the optimal plan. The results obtained and the actual conditions of the industry's evolution must be carefully compared. The tool used in this analysis is a system of dual estimates of the optimal plan.

Summary not reviewed by the authors of the model.

I.A.E.A.

The Model		Team of International Atomic Energy Agency staff members, Vienna, 1973[41]. Nuclear Power Market in Developing Countries.
Subject and Goal		- Potential role of nuclear power in 14 developing countries, size and timing of the installation of nuclear power plants. - Identification of the specific market for small and medium power reactors. - Estimate of the financial requirements in each of the countries for the selected programs.
System Described		The report mainly consists of a program called "WASP" (Wien Automatic System Planning Package), designed to find the optimum power system expansion plan within established constraints for any given country. To obtain the inputs several models were built; in particular, a long range forecasting model of the demand for electrical energy (by H. Aoki); a forecast of future fossil fuel prices; a model of nuclear fuel cycle costs; a model of generating plant capital costs.
Area	Time	Period from 1980 to 1989.
	Space	Argentina, Bangladesh, Chile, Egypt, Greece, Jamaica, Kenya, Mexico, Pakistan, Philippines, Singapore, Thailand, Turkey, Yugoslavia.
Modelling Techniques		Correlations, probabilistic simulation, dynamic programming, and near optimization techniques are used in different parts of the report. 1) Forecast of electrical energy demand. A. Aoki found a good correlation between the growth rate of gross electricity generation per capita and that of per capita GNP at factor costs for all countries during 1961-1968. He derived a "universal polynomial curve" and a bundle of neighboring curves converging to the universal curve for the upper values of GNP per capita and gross electricity generation per capita. The forecast for a given country is then directly obtained by following that curve of the bundle that fits best to its own past path. (The growth rates of the GNP and of the population are given by experts of the respective countries.) 2) The Wien automatic system planning package (R.T. Jenkins). This package consists of six modular programs: - A program to describe the forecast peak loads and load duration curves - A program to describe the existing power system and all firmly scheduled additions - A program to describe the alternative plant which could be used to expand the power system - A program to generate alternative expansion configurations - A program to determine whether a particular configuration has been simulated and, if not, to simulate operation with that configuration. Using a probabilistic simulation model, energy generation by each plant and the corresponding operation cost are calculated. The reliability of the generating system and the probable amount of unsatisfied demand are estimated. - Using the data files created by the other modules together with economic inputs and reliability criteria, the last program chooses the lowest cost expansion schedule for adding new units to the system over the period of interest. The objective function of this (dynamic programming) optimization is the present-worth discounted value of: all operating costs plus all capital investment costs of the variable-system less a salvage value credit at the horizon for the remaining economic life of its plants. 3) An independent model "ORCOST" gives all capital costs of generating plants with the cost adjusted to the specific country's cost levels.
Input Data		Program users must enter data describing the specific power system and economic system of their country, i.e. - Data describing load duration curves seasonally - Data on fixed generation system: thermal plants, hydro capacity, pumped storage - Data on manpower and length of working week, material equipment costs, interest rates.
Output Data		The main output data are: the projected annual nuclear plant additions by country; the financing requirements by country for all thermal plants to be commissioned during 1980-1989; the financing requirements for nuclear fuel cycle investments.
Observations		The linkages with the social and economic system are discussed in the report but not directly included in the models. The introduction of nuclear technologies in developing countries will have external effects that should be taken into account.

Summary not reviewed by the authors of the model.

MODELS CLASS B

JAPAN

The Model		Institute of Energy Economics, Tokyo, 1973[42]. Simulation of Future Oil Flow.
Subject and Goal		Optimal structure of world oil flow and oil industry in the future. Case studies combine four key factors of special importance in drafting future oil policy: 1) production reduction by oil producing countries, 2) development of oil fields in new areas, 3) introduction of substitute fuels, and 4) conservation of oil consumption.
System Described		This model is concerned with the optimum distribution of oil resources and substitute fuels, which is determined by such factors as oil production, oil consumption, refinery operation and introduction of substitute fuels.
Area	Time	Static model for a specific point in time (in 1980 and 1985).
	Space	World - 18 countries.
Modelling Techniques		Optimization model using linear programming. The optimal solution is constructed for cost minimum at profit maximum. The model comprises: (Standard Case / Case Study) equations: 336 / 340 variables: 2,869 / 2,956 non-zero elements: 16,734 / 17,702 density: 1.55 % / 1.58 % computing time: 7 minutes / over 7 minutes The volumes of 32 crude oils and 8 substitute fuels are determined by a supply step function. To reduce the oil consumption, cost penalties are imposed.
Input Data		Crude oil: 32 kinds, production, FOB price, yield and sulfur content Oil demand: demand by countries and by products (gasoline, naphtha, middle distillate, heavy fuel and other products) Refinery: capacity of topping, cracking and desulfurization, refinery cost, operation factor and allowance for expansion Freightage: tankers for crude oil and oil products Pipeline: for crude oil and oil products Other: sulfur specification, LNG, direct burning of crude oil and substitute fuels (tar sand, oil shale and liquefied coal).
Output Data		The model gives the flow of crude oil and oil products among 18 countries, total cost (FOB price + freightage + customs duty + refining cost) for each country, and shadow price for each crude and each substitute fuel. For the case studies, the model gives the level of crude production, the conservation level of oil consumption and the introduction of substitute fuels.

Summary supplied by the author of the model.

U.K.

The Model		Energy Research Unit, Queen Mary College, London, 1973 [43]. World Energy Modelling: Concepts and Methods.
Subject and Goal		In this model the aim is to minimize the costs of resources used in satisfying a given demand for energy products. The world energy system is regarded as a social-political-economic system and is formulated in a set of linear equations. The system can be considered either as being fully competitive or as a monopoly. The model studies both the long-term and short-term aspects.
System Described		The model considers the world as consisting of 25 discrete geographical areas; 52 kinds of crude oil are represented, and 22 refining centers (with available and future capacity determined by the model) are considered. The transportation system is reduced to 6 size categories of ships.
Area	Time	Static model for certain target years. Detailed results are calculated only for the chosen year - 1977.
	Space	The areas in the model have been chosen on the basis of the size of their energy demand, the significance of their location and their indigenous energy sources; e.g. Scandinavia, UK including Ireland, FRG including half of Switzerland and Austria, Benelux countries, France including the other half of Switzerland.
Modelling Techniques		The model is defined in linear programming terms. The optimal solution of the world energy model for any one year will be that set of opportunities (activities of industry) which will satisfy all the restrictions at minimum cost. The objective of the model is to minimize the total expenditure incurred to meet a given demand. The restrictions cover all aspects of the industry systems, e.g. those of availability, mass balance, quality, politics. Environmental factors are not considered.
Input Data		The complete matrix of the model contains 3550 rows and 13,500 columns. The following oil and gas processes are included: 1. Crude distillation Unit (CDN) 2. Vacuum distillation 3. Alkylation 4. Catalytic reforming 5. Desulfurization 6. Kerosene and gas-oil hydrocracking 7. Catalytic 8. Residue desulfurization 9. Residue coking 10. Natural gas liquefication 11. LNG regasification 12. SNG production. The refined products considered are the following: 1. Liquid petroleum/gas 2. Motor spirits 3. Petrochemical feedstocks 4. Kerosene/ATK 5. Gas-oil 6. Residual fuel oil 7. Bitumen 8. Coke.
Output Data		- New refinery plant capacity, by area, to be added in the chosen time. - The world wide total of new plant capacity. - The total of new oil tankers to be constructed to meet the demand pattern of the chosen time. - The capital to be invested between the current time and the chosen time horizon. - The prices, $ per bl, of the products. - The imports of crude oil and products into the various areas. - The equilibrium prices in the fields for crude oil.
Observations		It seems that some exogenous parameters (such as future demand, cost, refinery, technology) are difficult to forecast. The model does not take the environmental aspect into account. It does not give a dynamic view; only a comparative static view is possible. The work of the Energy Research Unit of QMC is at an early stage and many more studies are underway.

Summary not reviewed by the author of the model.

U.K.

The Model		Energy Research Unit, Queen Mary College, London, 1973[44]. Development of Western European Oil Prices .
Subject and Goal		The goal of this study is to verify some of the economic concepts of the world energy model built by the Deam group, and some preliminary results of that L.P. model: - That in the short run product prices reflect cost changes - That in the long run product prices are determined by the price of crude oil and the cost of refining.
System Described		The verification is made with the following data for the European oil market: a) A composite price series consisting of weighted prices of 3 petroleum products (gasoline, gas-oil and fuel oil) is correlated with the exponentially smoothed costs, i.e. the sum of prices of marginal crude oil from the Persian Gulf and its transportation cost to Western Europe. The relationship between the $ price of the individual product and the smoothed marginal cost of crude oil is then calculated. b) The long-term product prices are given by a linear equation model, taking into account the cost of crude oil, total cost of the various refining and cracking methods, and yields of the various refined products and their residue per ton crude. The comparison of these prices with the calculated price-cost ratios shows, the authors say, that this model is satisfactory. c) To explain future trends of the price structure, development of desulfurization of oil and increased conversion to SNG has to be taken into account and of the model described in b) must be modified. Preliminary results obtained in the LP world energy model for 1977 are briefly described.
Area	Time	1966 - 1972.
	Space	Western European oil market.
Modelling Techniques		a) Exponential smoothing of the cost series; linear regression analysis. b) Small model consisting of 4 linear equations. c) Modification of b).
Input Data Physical		Yields of various refining methods (atmospheric distillation, vacuum distillation and catalytic cracking) per ton Kuwait crude.
Economic		- Daily prices of petroleum products, Western Europe. - Consumption of these products in OECD areas. - Prices of crude oil in the Persian Gulf, determined mainly by royalties, and taxes levied by the government of the producing country. - Costs of various refining methods (both capital and operating costs) and of desulfurization.
Output Data		- Short run prices of oil products per ton, relative to smoothed marginal cost of crude oil. - Long term prices of oil products.
Observations		The correlation coefficient for the short term is not given, nor is the comparison of long term prices with short term prices.

Summary not reviewed by the authors of the model.

U.S.A.

The Model		H. Houthakker and M. Kennedy, 1974[45], Harvard University, Cambridge, Mass. World Petroleum Model.
Subject and Goal		The goal of this model is to describe the world oil market structure, to present some illustration runs for forecasting and policy simulation, and to simulate the effect of changes in exogenous factors, such as tanker technology or the cost of finding and producing oil in more remote areas, as well as government policies on trade, environmental restrictions and taxation.
System Described		The model consists of 4 segments: crude oil production, transportation, refining, and consumption of products. It is a regional multi-market general equilibrium model of the international oil industry.
Area	Time	So far, only the results for 1980 have been published.
	Space	The world oil market, divided into 6 regions: USA, Canada, Latin America, Europe, Persian Gulf, Asia and Africa.
Modelling Techniques		This model uses simulation techniques but with equilibrium equations obtained through economic theory. The different equations can be interpreted as first order conditions of a quadratic programming problem describing a competitive market. The equilibrium position of the world oil market in the long term is determined by 4 matrix equations and inequalities: - One postulates that the supply of crude oil and the demand for products in each region depend linearly on all prices in the world market - Another translates the fact that the revenue for operating any activity must be less than or equal to the cost of operating the activity - Another gives the material balance - The last assumes that the optimum is obtained for this competitive market; it specifies that if activity is used, the revenue equals the cost of operating this activity. (The model can also be used to simulate the actual oil economy for the very short term; in this case the equations are slightly changed to take into account the fact that: the price elasticities of supply and demand are different, there are additional constraints of capacity, capital is not freely transferable among different uses.)
Input Data		At present the model is running with 30 (6 x 5) commodities: 6 regions (see Area), 5 kinds of fuel: crude oil, gasoline, kerosene, distillate fuel, residual fuel. (The model could be extended to larger versions.) In each region, the exogenous variables are: In the demand sector: - underlying rate of income growth - income elasticity of demand. - price elasticity of demand - level of excise taxes on refined products In the supply sector: - price elasticity of crude oil supply - availability of crude oil from new sources (Alaska) - possible development of petroleum liquids based on shale oil or coal at a user specifed cost - government subsidy of oil production through price support - overall level of refining cost in future years - mix of products with respect to environmental quality - refinery siting subsidies or restrictions - different costs of refining With respect to trade: - export taxes or quotas imposed by OPEC countries - implications of Canada or Norway becoming producer cartel members - effect of import duties or quotas by consuming countries - changes in level of refining cost and transportation rate - implications of the development of deepwater ports.
Output Data		For each region and each commodity (crude oil or refined product), the model determines the level of consumption, production and price, refinery capital structure and pattern of world trade flows.
Observations		The model is still developing. Only some results for the 1980 simulation have been published, mainly giving the impact of two parameters: the Persian Gulf export tax (either \$3.50 or \$7 per bl.), and the response of North American oil supply to changes in price (both elasticities, .25 and .67, have been tested). The results affect e.g. the level of the reserves of Persian Gulf and North African supplies: the income of these producing countries was never above 23 billion dollars (1973 \$) a year.

Summary not reviewed by the author of the model.

MODELS CLASS C

AUSTRIA

The Model		G. Tintner, 1971 (46), Technische Hochschule, Vienna. Consequences of a Possible Energy Crisis in Austria.
Subject and Goal		A linear programming study of the Austrian economy in case an energy crisis arises, based on an input-output model. The objective function is maximum employment.
System Described		Decrease in utilization of oil products in the case of a crisis, assuming that indigenous oil production is kept constant.
Area	Time	Model of short-term behavior in the case of an energy crisis; 1970 values are used in the simulation.
	Space	Austria
Modelling Techniques		Optimization model with linear programming. Maximization of the total wage income as the objective function; limitation of consumption (gross production + imports) as activity vector; integration of the foreign trade and household sectors in the I/O matrix.
Input Data		The input-output table for 1970 (aggregated from 31 to 17 sectors) of the Bundeskammer der Gewerblichen Wirtschaft is taken as the basis: estimated wage coefficient for 1970 provided by the Institute for Econometrics. Three energy sectors: the petroleum industry, the mining industry including coal, and the electricity sector including natural gas.
Output Data		The percent decrease in gross production and total wages for each branch in the case of a supposed decrease in the utilization of oil products of 2, 4,... 20%.
Observations		This model analyzes the optimal allocation under conditions of a given political objective function. However, a sensitivity analysis of the coefficients of the technology matrix has yet to be carried out. It is proposed, in particular, to examine the effects of a replacement of oil by coal as an energy source in several branches of industry.

Summary provided (in German) by the author of the model.

CANADA

<table>
<tr><td colspan="2">The Model</td><td>J.G. Debanné, 1973[47], University of Ottawa, Ontario.
Model for Energy Supply vs. Pollution.</td></tr>
<tr><td colspan="2">Subject and Goal</td><td>The model is intended as a tool for planning and policy analysis by assessing the spatial, temporal, internal and external interactions of the components of the energy sector.</td></tr>
<tr><td colspan="2">System Described</td><td>The model describes the North American energy supply-distribution-consumption activity. It takes into account physical, political, technical and economic aspects. All forms of energy are considered, with special emphasis on gas and oil.</td></tr>
<tr><td rowspan="2">Area</td><td>Time</td><td>The model is static; it can be used to analyze short to middle term decisions.</td></tr>
<tr><td>Space</td><td>North America broken down into political regions.</td></tr>
<tr><td colspan="2">Modelling Techniques</td><td>- Network flow model.
- Network optimization, using the "out-of-kilter" method for minimal cost flow problems of D.R. Fulkerson.

The nodes of the network represent: oil, natural gas, coal and hydro production centers; nuclear energy generation centers; demand centers. The arcs of the network are pipelines and other transportation modes which distribute the flows of energy from the production to the demand centers. They are characterized by an upper and a lower bound to flow, a unit cost and a loss coefficient.
According to the nodes connected by the arcs, the interpretation of the characteristic parameters changes: e.g. the unit cost can be a field price or a pollution control cost, the lower limit can be a "guaranteed production" or a non-substitutable demand, etc.
The objective function to minimize is the total cost of satisfying the minimum throughput levels, subject to maximum capacity constraints.</td></tr>
<tr><td colspan="2">Input Data</td><td>- Minimum demands for each energy commodity and total energy demand at each demand center.
- Transmission, storage and pollution control costs for each commodity.
- Producing capacities at every source node and transmission capacities in every transmission list.
- The price structure of energy at the previous time period.
- Energy conversion efficiencies.</td></tr>
<tr><td colspan="2">Output Data</td><td>The optimal flows through the network and their shadow prices or opportunity costs.</td></tr>
<tr><td colspan="2">Observations</td><td>The optimization algorithm can always provide a feasible solution because a "slack" node has been introduced into the model.
This node has available an expensive slack source of energy which is priced at the generation cost of pollution-free nuclear power, to be used only as last resort. This permits ensuring the computational feasibility without distorting the optimal allocation of the other energy resources.</td></tr>
</table>

Summary not reviewed by the author of the model.

CANADA

The Model		Institute for Policy Analysis, University of Toronto, 1973[48]. Econometric Model for Energy.
Subject and Goal		The object is a complete econometric model of supply, demand and transformation (transportation, refining, etc.) tied to a macro-model of the Canadian economy.
System Described		The model will be used to trace out alternative scenarios given policy prescriptions, including feedbacks from energy to the macro-system.
Area	Time Space	Time series, cross section, Canada, tied to similar work being undertaken at Data Resources Inc. in Cambridge, Massachusetts, U.S.A.
Modelling Techniques		Econometrics and linear programming.
Input Data		(Too varied to list.)
Output Data		Impacts on energy use and the macro-environment of alternative assumptions of policies and exogenous variables.
Observations		A three-year project, whose first step is a detailed demand analysis.

Summary supplied by the author of the model.

CANADA

The Model		Rick Hyndman, 1973[49], University of Toronto. Residential and Commercial Demand for Energy.
Subject and Goal		Simultaneous equation model in the A.P. Barten style aimed at eliminating aggregation errors present in ordinary least-squares estimates of fuel use.
System Described		Substitution of different fuels in fulfilling household and commercial demand.
Area	Time	Time series, dynamic stock adjustment.
	Space	Canada.
Modelling Techniques		Non-linear simultaneous equation econometrics.
Input Data		Vectors of demands, prices, stock of energy using appliances, income.
Output Data		Elasticities of demand for energy use when the required constraints from demand theory have been imposed.
Observations		This approach should be used for other sectors also.

Summary supplied by the author of the model.

CANADA

The Model		Leonard Waverman, 1973[50], University of Toronto . Linear Programming Transportation Models .
Subject and Goal		Linear programming models of energy commodities designed to minimize final costs to consumers.
System Described		Operational now are l.p. models for natural gas and coal. The objective is to determine least cost paths and the effects on costs of constraints imposed by governments.
Area	Time	One given year, static model, 1972 data.
	Space	North America; could be applied to any region.
Modelling Techniques		Linear programming.
Input Data		- Any fuel could be used, e.g. gasified coal. - Needs vectors of demand, production costs, transport costs, capacities, transformation costs. - No ecological inputs.
Output Data		- Optimal networks. - Costs of interfering with these networks.
Observations		Attempting to incorporate demand and supply functions.

Summary supplied by the author of the model.

C.S.S.R.

The Model	Bohuslav Cabicar et al., 1973[51], Energy Research Institute, Prague. Structural Model of Fuel and Energy Economy.
Subject and Goal	Optimal technological structure of the fuel and energy economy of Czechoslovakia; it implies the optimal volumes (mining, production and import) of significant types of fuel and energy forms.
System Described	The model studies the fuel and energy economy as one system, and the sub-systems of electric power, centralized heat supply, gas industry, coke manufacture and petroleum refining.
Area – Time	Static model for the optimization in a time area of about 15 years (5-year time sections up to 1990).
Area – Space	Czechoslovakia as a whole.
Modelling Techniques	Structural model by means of which optimization considerations are made indirectly on the basis of balance and economic evaluations of an explicitly given discrete set of variants. The formulation of variants arises from the possible substitution of energy forms and technological processes, to have a better knowledge of the impact of different production processes, and of consumption. The criterion for the choice of the optimal variant is the minimum annual cost in the fuel and energy economy.
Input Data – Physical	- Matrix of technical coefficients expressing the internal technological connections within the fuel and power economy. - Demand vector of final useful consumption. - Vector of limiting factors (available resources). The model does not deal with ecological factors.
Input Data – Economic	Vector of the specific non-energetic costs of energy forms. The individual matrices and vectors consist of the following forms: 1. Black coal for coking process 2. Black coal for energetic purposes (sized) 3. Black coal (unsized) 4. Lignite coal (sized) + briquettes 5. Lignite coal (unsized) 6. Coke metallurgical 7. Coke (other) 8. Crude oil 9. Petrol 10. Diesel and fuel oils 11. Light fuel oils 12. Heavy fuel oils 13. Gases from refineries 14. Petrochemical products 15. Natural gas 16. Gas from cracking of natural gas 17. Gas from cracking of petrol 18. Gas from gasification of lignite coal under pressure 19. Coke-oven gas 20. Coke-oven gas used as town gas 21. Town gas 22. Generator gas 23. Blast furnace gas 24. Heat from heating plants (coal) 25. Heat from heating plants (liquid and gaseous fuels) 26. Heat from heating and power plants (coal) 27. Heat from heating and power plants (liquid and gaseous fuels) 28. Heat in systems 29. Electricity from steam power plants (coal) 30. Electricity from steam power plants (liquid and gaseous) 31. Electricity from nuclear power plants (aquous homogeneous reactor) 32. Electricity from nuclear power plants (fast reactor) 33. Electricity without capacity demands 34. Electricity from hydro-electric power plants 35. Electricity from pumped storage power plants 36. Electricity from electric power plants with gas turbines 37. Electricity in the power system 38. Electricity in the power system (without capacity demands)
Output Data – Physical	Vector of the optimal volumes of individual types of fuel and energy forms classifed by substitutive technologies.
Output Data – Economic	Vector of the total specific cost of individual types of fuel and energy forms classified by substitutive technologies. Volume of the annual costs of optimal variant.
Observations	The model can also be used for the direct optimization of the energy economy, using linear programming.

Summary supplied by the author of the model.

DENMARK

The Model		Sven Bjørnholm, 1973[52], University of Copenhagen. Alternative Organizations of Society in Terms of Energy Use.
Subject and Goal		Two scenarios - "Growth as Usual," with a 4-6% annual increase in total energy imports over the next 30 years, and "Reduced Growth," with a 2-3% increase - are to be constructed. How much will the balance of payments, investments, traffic, housing patterns and general life style differ between the two alternatives? What are the main elements of an energy policy required to implement one or the other scenario?
System Described		The Danish energy system: electrical power, house heating, industry, transportation, agriculture.
Area	Time	1973 - 1988 - 2003.
	Space	Denmark.
Modelling Techniques		Input-output tables of the Danish economy are used to forecast energy consumption from projected total demand. Estimates based on concrete studies of known and possible future techniques in the energy field are used to revise the technical coefficients of the input-output matrices.
Input Data		- The energy mix in supply and consumption 1950-1970. - The 1966 input-output tables of the total economy. - The two alternative growth rates (see above). - The projected input prices of energy raw materials. - Capital requirements for the implementation and running costs of known or new techniques in the field of more efficient energy conversion and use, and in the field of alternative energy resources.
Output Data		The two scenarios mentioned under Subject and Goal.
Observations		- The project will not make use of computer based systems analysis techniques. It may be viewed as a forerunner of a more quantitative study being prepared at the Technical University of Denmark (N. Meyer, E. Mosekilde). - The project started April 1, 1974 and will be completed in two years. It is sponsored by the International Federation of Institutes of Advanced Study, IFIAS.

Summary supplied by the author of the model.

F.R.G.

The Model		Zentrum Berlin für Zukunftsforschung, Berlin, 1972[53]. ENIS Information System for the Energy Sector.
Subject and Goal		This project, sponsored by the Bundesministerium für Forschung und Technologie, basically is an attempt to deal with special problems of energy policy by means of a complex EDP-aided information system, which should provide all the necessary information on past and future developments of the energy economy in the FRG. The information to be obtained should not only refer to the field of energy production and consumption but also include effects on the environment due to changes in energy use.
System Described		The information system consists of a data bank, a simulation model and application models. The data bank supplies all data necessary for the operation of the simulation model, in which the energy economy of the FRG is described by means of three programs. The "base" program establishes an energy balance using demand forecast, a given demand structure and a given import/export situation. An energy balance sheet giving the amounts of each type of energy produced is obtained by considering: - net efficiencies of transformation of primary fuels to secondary energy supplies, - transportation losses, - user efficiencies. In the "environment" program the energy balance previously established is used to disaggregate environmental burdens according to types of emissions and sectors which produce them. By means of the "cost" program, the economic consequences of the introduction of environmentally protective technologies in the field of energy production are determined.
Area	Time	The period of investigation is variable. An upper time limit may result from limitations of the forecasting method used (trend extrapolation).
	Space	The model applies to the Federal Republic of Germany.
Modelling Techniques		- Data bank organization: the descriptors used are logically linked to each other. - Transformation matrices are used to establish the energy balance and determine environmental burdens. - Methods of regression analysis and trend extrapolation.
Input Data		The data required are stored in the data bank as follows: - Historical consumption and production of primary and secondary energy, conversion and user efficiencies - Emission data of various conversion areas - Costs of primary energy, transportation, conversion and environmental protection measures.
Output Data		In principle all information that is stored in the data bank can be retrieved. The simulation model is expected to supply all relevant data on the future development of the energy economy.
Observations		The models should be completed by late 1974 but complete data will not be available until later. The model will possibly be regionalized.

Summary not reviewed by the author of the model.

F.R.G.

The Model		M. Liebrucks, 1973[54], Deutsches Institut für Wirtschaftforschung, Berlin Econometric Models for the Energy Sector of the F.R.G.
Subject and Goal		Projection model for the energy demand of the F.R.G. The results should assist in decision-making in the energy field. The model relates to the energy economy only and does not refer to any secondary effects such as e.g. the reduction in the number of jobs in the case of decreasing production of hard coal.
System Described		To determine the energy demand, the model operates in three steps. First the final energy demand is calculated by economic sectors and by forms of energy as a function of the specific demand and explanatory variables, e.g. the net production values in the different industrial sectors. The inter-industry relationships are taken into account with the help of input-output tables. The second step draws on the results of the first for secondary forms of energy and establishes the necessary input of primary energy. In the last step, the end use (Step 1) and the demand of the transformation sector (Step 2) are aggregated to arrive at the demand for primary energy. The model takes into account 40 individual forms of energy, 29 groups of consumers in the end use sectors and 14 techniques in the transformation sector. It does not contain any method for the forecast of imports of secondary forms of energy.
Area	Time	The model deals with short and middle range projection of energy.
	Space	The model was developed for the Federal Republic of Germany.
Modelling Techniques		The model is an econometric one. It uses different types of regression functions and the normal projection methods to solve the forecast problem. The inter-industry relationships are described by an input-output table. Several statistical tests are incorporated. Test criteria are the correlation coefficient, the coefficient of determination, testing of multilinearity and autocorrelation of the residues.
Input Data		For a basic period of 10 years the maximum input might amount to 31,000 data points. The main input data are: - Basic data of the energy economy from the energy balance sheet - Basic data of the explanatory variables in the end use sector (industry, household and small consumers, transportation) and in the transformation sector.
Output Data		The data output depends on the type of information required. The most important are projections of: - Final energy demand by sectors and by forms of energy - Specific energy consumption - Energy demand in the transformation sector - Primary energy consumption.
Observations		The input of the model is very detailed. The model does not operate in an integrated manner. The results of Step 1 (calculating final energy demand) must be checked as to their probability, because in a number of cases function statements which are justified from the econometric point of view supplied results which cannot be justified in practice, especially in the case of long-term projections.

Summary not reviewed by the author of the model.

HUNGARY

<table>
<tr><td colspan="2">The Model</td><td>F. Rabar, 1970[55], Laboratory for Information Processing, Budapest.
Investment Policy in the Energy Economy.</td></tr>
<tr><td colspan="2">Subject and Goal</td><td>The aim of the research is to determine an optimal investment policy for the energy economy as a whole. However, this would be overly ambitious; a more modest and more practical aim is to develop a simulation model to investigate the consistency and consequences of a proposed investment policy.</td></tr>
<tr><td colspan="2">System Described</td><td>The system described is that of energy demand and supply, taking the technical and economic aspects of supply into consideration. The demand takes the prices and the possibilities of substitution between the various forms of energy into account. The structure of the energy system and the energy economy (distinction made by the author) is studied in detail.</td></tr>
<tr><td rowspan="2">Area</td><td>Time</td><td>The general method is used for the long term but a number of procedures are also applicable to the short term.</td></tr>
<tr><td>Space</td><td>Not specified.</td></tr>
<tr><td colspan="2">Modelling Techniques</td><td>The system to be modelled consists of 3 characteristic structures: production, conversion, and consumption. These are interdependent and may change with time. To describe this system 3 simulation models have been formalized to investigate the problems in increasing order of complexity:
1) A static, aggregated description of technical relationships. Fixed demand, no choice in input-output structures.
All producing and converting capacities are summarized but the distribution in space is not described, thus excluding possible representation of a transportation system. The shortage or excess of production capacity for the different types of energy are computed.
2) A dynamic model of disaggregated technical relationships, exogenous (and perhaps stochastic) dynamic demand, limited substitution of input factors and transportation systems. Demand consists not of single figures for every energy form for the entire period of the forecast, but of extrapolated trends of these, reflecting also seasonal fluctuations. The production scheme corresponding to different hypothesis on surplus and shortage are introduced for each energy form at each step of the calculation. The technology of transport is included.
3) Economic, dynamic, decentralized; choice of input and output; changing demand; interaction between demand and supply structures, short run adjustments in prices and quantities; limited capacity of transportation system. New parameters: regions, substitution pattern and efficiency. The state of the system is described in a more sophisticated way, including exports, imports, income, total cost, unit costs, benefit-cost ratio, price and demand for every energy form (the model contains changing prices with an automatic adjustment to the supply and demand situation of the market).
With the output of 2), we can simulate the consequences of any investment or group of investments in every part of the system by changing the input parameters affected by the investment from time t, the planned start-up time of new projects.</td></tr>
<tr><td colspan="2">Input Data</td><td>The following matrixes are given:
TECHN: the quantity of energy i necessary to produce one unit of energy j.
STRUCT: the proportion of i to the other input in producing one unit of j.
PRODU: the produced quantity of j during the given unit of time, when using i as input material.
TRANSYST: the distance expended in time units between i as the place of production of the i-th material and the production place of the j-th form of energy.
DEMAND: the projected demand of j for a future period t. In model 3, the demand is endogenous.
The other matrixes are concerned with: the inventory of material and product, cost of production, transportation cost, import price, export price, useful energy demand, interest rate, etc.</td></tr>
<tr><td colspan="2">Output Data</td><td>- Surpluses and shortages for every energy form.
- Actual inventory of material and of product.
- Orders generated during one time unit at production place i for product j.
- Import requirement and export probability.
- Actual cost of one produced unit and income from the quantity sold.
- Benefit-cost ratio calculated from the costs incurred and income generated.</td></tr>
<tr><td colspan="2">Observations</td><td>- For each model the different steps of the simulation are described.
- The connections between the macro- and micro-economic models are clearly stated.
- The advantages and disadvantages of the models are studied.
- The general problem of choice among the different indicators representing the efficiency of investment policy is examined.
- The significance of technical changes, depreciation and absolute investment is described.</td></tr>
</table>

Summary not reviewed by the author of the model.

RUMANIA

The Model		M. Petcu, Pap, Kovacs and Liciu, 1971[56], Institut de Recherches d'Energétique Industrielle et de Projets d'Outillages Energétiques, Bucharest. Multi-Energetic Supply Model.
Subject and Goal		The goal of the model is the planning of the energy sector so as to obtain the most economical form of production which assures that the consumption requirements are covered, and takes into account available resources and existing investments or plants to be constructed.
System Described		The model describes the energy supply system. The unknowns are of 2 kinds: the new capacities to be installed at each stage of the optimization period, and the energy flow in the last year of each stage. To facilitate decision-making, several variations are studied, showing the impact of a number of important factors and the repercussions of the development of this or that use of energy (technological variants).
Area	Time	A number of decades (no exact specification).
	Space	Rumania, mainly.
Modelling Techniques		The optimization model uses linear programming. From a number of simplifying hypotheses the costs realized for investment and operation in each period are first calculated. Then a set of constraints is considered: - Linking the production and intermediate and final consumption of the various forms of energy, and the capacity of the plants, at each stage - Analyzing the technological variants: a given use may be satisfied by several technologies, each consuming a certain quantity of energy. The model is conceived so as to select the most economical technology - Taking into account the limited fuel reserves: by means of the constraints, the estimated reserves, the reserves already obtained and the reserves in the process of being won (unknowns of the model) are ascertained - Integrating the running of the electric power stations of 3 types: hydro, thermal and nuclear, each the object of specific constraints.
Input Data		There is a large amount of entry data since the energy supply is defined in all its details. Apart from the aforementioned variables, some of the parameters are: - Investment and operating costs of the plants - Coefficients of transport and distribution losses - Coefficients of transformation of one form of energy into another - Coefficients of the ratio of the plants to "joint production" - Coefficients of the ratio of the plants to the complementary forms of energy - Coefficients of specific consumption for each use of energy - Specific coefficients appropriate to the power stations.
Output Data		Most of the variables of the model have already been defined: the investments to be made, the energy production and the intermediate consumption of the various plants. For each use, the final demand is broken down into specific and substitutable consumption, the latter being important for determining the most appropriate technology for each use.
Observations		While the mathematical formalization of the model is, on the whole, classical, there is one point which may be considered original: the explicite notion of the use of energy. It is through this means that the phenomenon of substitution of different forms of energy is best interpreted.

Summary not reviewed by the authors of the model.

U.K.

The Model	Model Group of the Department of Energy, London, 1972 (57). U.K. National Energy Model.
Subject and Goal	The long term aim of this model is to balance supply and demand for each kind of fuel in each market over time. The main goal is to evaluate the investments needed by the energy fields which represent approximately (in 1974) 8% of the total UK investments.
System Described	The model is an energy model for the UK as a whole and for each energy sector. It breaks down the energy probelm into a number of sub-models. For the time being (April 1974) it is not completely finished, and only a snapshot of the situation can be given. So far 4 sub-models have been developed: - a demand sub-model - a gas supply sub-model - an electricity supply sub-model - a coal supply sub-model. An oil supply sub-model and the linkage between the sub-models are being developed.
Area – Time	The horizon is the year 2010.
Area – Space	UK as a whole.
Modelling Techniques	All supply sub-models are optimization models using linear programming. The demand model is a multiple linear regression.
Description of the Sub-Model	Demand Sub-Model For each kind of fuel and each economic sector, the demand is represented by a multiple linear regression between the logarithm of energy consumption and the logarithm of four parameters: - an activity indicator for the studied sector - the price of the fuel - the temperature - the time. The different sectors are: domestic, industrial, commercial, public administration and transport.
	Gas Supply Sub-Model The gas supply sub-model is an allocation model using linear programming. The model considers the activities of distribution, transmission and storage of natural gas, mainly of the North Sea, entering the country through only a few terminals. The objective function is the minimization of the supply cost. For each activity, all costs (e.g. for distribution per therm, building a plant or pipeline, running it, etc.) are multiplied by a weight representing the number of years and days associated with that variable, and the discount factor. The different constraints and relationships are: - the gas demand relationship; in particular, there is an upper limit to the amount of gas which can be sold to any market at a given price - the gas balance relationships: the output must exceed the uses and the imported gas must either be distributed or transferred to storage - the upper limits to contracts for import - the plant capacity constraints - the storage: gas withdrawn from storage must have been stored there.
	Electricity Investment Sub-Model The electricity sub-model is divided into 2 versions: one devoted to investment decisions, the other to the detailed operation of the system in a single year. The two models interact. The model does not yet run with all the expected details. In the present formulation (others are in development) the objective function used is the total (capital cost, operating cost and fuel) discounted system cost over the period studied. No geographical breakdown of the energy supply is made; it is a "point" model. The main physical constraints are: - the future load and pattern of the demand (the model uses linear interpolation) - the physical characteristic of each plant used: coal, oil, gas or nuclear fuel (including the plutonium balance when the FRB is introduced).
	Coal Supply Sub-Model The aim of the coal model is to predict the average and marginal pithead cost, the productivity and the manpower needed at any output level in any future year up to 2010. This model deals with the minimization of production cost. The main cost function used is the production function per ton which is taken as a linear function of the volume production.
	Oil Supply Sub-Model This model is unfinished.
Observations	So far the 4 sub-models are running separately. The main effort of the team which has developed them is the linkage between them. Three main approaches are studied: - modular: each model is run separately and the output of one is used as input for another - monolithic: development of a single LP model using a single objective function - mini-model: all problems and models are simplified with the goal of more quickly reaching a compatible solution.

Summary not reviewed by the authors of the model.

U.S.A.

The Model		Martin L. Baughman, 1972 (58), Massachusetts Institute of Technology, Cambridge, Mass. Dynamic Energy System Modelling - Interfuel Competition.
Subject and Goal		- Dynamic model of interfuel competition. - Study of behavior of supply, demand and prices for the different forms of energy. Application to 3 case studies to demonstrate the possible uses of the model to assess the effects of new technologies or policy issues.
System Described		The energy system described consists of: - A demand sub-system: residential and commercial sector, industrial heating sector, transportation sector, electricity sector - A supply sub-system for the following fuels: coal, natural gas, petroleum, nuclear electricity - A resources sub-model that indicates which resources to develop. Imports, demand by sectors, exploration are exogenous.
Area	Time	1947 - 1993.
	Space	USA as a whole.
Modelling Techniques		Simulation of the dynamic behavior of the system. Principal assumptions of the model: - Total demand inelastic - Short run supply cost functionals - Perfect competition framework: primary fuels priced at marginal development costs; electricity priced at average cost - Demand is broken down into a "base demand" and a "market sensitive demand" - Base demand of each sector is a fraction of the total sector demand - Demand sensitive to market prices is distributed among the different sectors; the distribution factors which determine it are a function of the energy prices.
Input Data Physical and Economic		- Time series of additions to reserves and cost of developing these reserves. - Marginal development cost curves. - Time series of total demand by consumption sectors. - Parameters of the base demand. - Distribution factors of the sensitive demand and their price elasticities. - Time series of imports. - Capacity utilization factor of electricity generating plants.
Output Data		- Market shares and levels of consumption for the different fuels. - Prices.
Observations		- 1947-1969 time series were used only to partially validate the structure of the model. - Poor justification of some coefficients used. - The model could be disaggregated regionally and by fuel products and quality. - Exploration could be internalized, as could other feedback structures.

Summary not reviewed by the author of the model.

U.S.A.

The Model		Edward G. Cazalet, 1974 (59), Stanford Research Institute, Menlo Park, California. SRI Energy Modelling Capability.
Subject and Goal		SRI has developed methods of constructing models for complex markets characterized by interproduct competition and regional differences arising from product transportation costs. This work permits rapid construction of comprehensive energy models to support analysis of strategic energy-related corporate decisions and various aspects of government energy policy.
System Described		A national energy model in support of a decision analysis of synthetic fuels strategy, developed for a U.S. oil company. The purpose was to compute market clearing prices and flows by balancing supply and demand in an economic framework.
Area	Time	1973-2025 using 17 time periods of varying length.
	Space	National with 8 demand regions and 30 supply regions (imports are considered); expansion to global scope possible.
Modelling Techniques		Successive approximations algorithm applying decomposition concepts over a network. Permits using nonlinear functions to model economic and physical relationships.
Input Data Physical		The model covers all major energy forms, conversion processes and transportation modes and explicitly models supply elasticity, interfuel competition and end use demands. The model needs knowledge of: - the levels of demand for energy for each end use sector, such as residential space heat in the New England market - the network of transportation links, production processes, conversion processes, distribution links and end use conversion processes that together represent the entire energy system - the thermal efficiency of each element of the system.
Economic		The model needs knowledge of the specific capital and operating costs of each element of the network, rates of technological improvement over time, and financial and tax information. Supply elasticity is described in terms of curves specifying the marginal cost of resource production as a function of cumulative consumption of the resource. Information on the price elasticity of important secondary industries, such as mining equipment and process construction, is required.
Ecological		Provision is made, but has not yet been used, for pricing emissions and incorporating these prices in the economics of the processes.
Output Data Physical		The flows over time that balance supply with demand under free market conditions and some forms of regulated, centralized and imperfect free market conditions.
Economic		The market clearing prices (over time for all major energy forms) that characterize the supply/demand balance.
Ecological		Can provide the volumes and social prices of emissions (not yet used).
Observations		Data requirements are not large but considerable processing of available data and subjective information is required. This has been done for the U.S. model. Price elasticity of end use demand is now handled outside the model, although the basic approach can include it. Competition among fuels to satisfy end use demands is included. Some skill in using the model is required because of its iterative nature.

Summary supplied by the authors of the model.

U.S.A.

The Model	E.W. Erickson, R.M. Spann, R. Ciliano et al., 1973[60], North Carolina State University, Raleigh, N.C. Substitution and Usage in Energy Demand .
Subject and Goal	Accurate forecasts of future fuel demands for national energy policy. Total market forecasts based on aggregate homogeneous BTU's are not critically relevant to the formulation of a national energy policy; forecasts should estimate the effects of various policies on each fuel in addition to integrating the interrelationship between fuels within the total energy concept.
System Described	The model describes the residential and commercial heating system: the demand for energy within each sector-fuel combination and the home heating decisions.
Area – Time	Forecast model for certain target years.
Area – Space	Certain regions of a national energy system.
Modelling Techniques	The model uses regression analysis. The formal statement is as follows: $s_{it} = a + b\underline{X}_t$ = the percentage of new constructive units using fuel i in time t, and $\underline{X}_t$ = the vector of variables affecting s_{it} $U_{it} = a' + b'\,\underline{Z}_t$ = average usage per consuming unit of the units using fuel i in time t, and $\underline{Z}_t$ = the vector of variables affecting U_{it} $S_{tt} = S_{it-1} + s_{it} - l_{it}$ = the market share of fuel i in time t l_{it} = the loss rate of market share for fuel in time t The demand for fuel i in time t then is $D_{itr} = S_{it} \times N_t \times U_{it}$, where N_t = the total number of households in time t. The home heating decisions are determined by the following variables: SOR = the ratio of oil burners installed in new dwelling units to total new construction SGR = natural gas heating customers added via new construction divided by total new construction PO = the average real price of fuel oil in $ per barrel to the residential market sector PG = the average price of natural gas in $ per ft^3 to the residential market sector U = an increase of urbanization Y = real income per capita S 1 = the % of new construction that is 1- or 2-family dwelling units S 2 = the % of new construction that is 4-family dwelling units or less T 1 = winter temperature AC = the number of private 1-family homes sold with air conditioning Dj = a set of dummy variables with the index for the several regions of a nation PE = the average price of residential electricity. The basic estimating equations are with these variables: $\log(SRG) = a_o + a_1\,(PG/PO) + a_2\,(PG/PE) + a_3AC + a_4U + a_5Y + a_6D1 + a_7D2 + a_8D3 + a_9D4 + a_{10}S2$ $\log(SOR) = b_o + b_1\,(PO/PG) + b_2\,(PO/PE) + b_3AC + b_4U + b_5Y + b_6T1 + b_7D1 + b_8D2 + b_9D3 + b_{10}D4 + b_{11}S2$.
Observations	The preliminary results of an example for the residential heating sector are given: for the incremental market share of natural gas the correlation coefficient (R) is 0.569, and for the incremental market share of oil R^2 is 0.587. For the results of an application of the model to the average usage rates of electricity R^2 is 0.853.

Summary not reviewed by the authors of the model.

U.S.A.

The Model	Kenneth Hoffman, 1972 [(61)], Brookhaven National Laboratory, Upton, L.I., N.Y. Planning Framework for Energy System Planning.
Subject and Goal	Optimal technical structure of the US energy system. The model reflects a wide range of energy technologies and interfuel substitutability. It traces paths from primary consumption to final demand for each type of fuel.
System Described	This model is concerned with the substitution of different fuels at the level of disaggregated demand and supply. In addition, it estimates the volume of each type of pollutant produced by the energy system.
Area – Time	Static model for a particular point in time (has been applied to the years 1985 and 2000).
Area – Space	USA as a whole.
Modelling Techniques	Optimization model using linear programming. The model provides a feasible path between n=13 exogenous supply categories and m=15 exogenous demand categories. The objective function is the minimized solution of the present cost of the possible paths. Three constraints must be satisfied: the level of each kind of demand, the possibility of each kind of supply system, and the levels of the different pollutions. An expanded model is under development with 27 supply categories and 22 demand categories.
Input Data Physical	n=13 supply categories are considered as follows: - 8 kinds of central stations that produce electricity as an intermediate energy form: hydropower, geothermal, coal-steam electric, LWR electric, LMFBR electric, gas turbine electric, pumped storage electric and solar energy. - 4 general purpose fuels that are directly delivered to consumers: oil products, natural gas, synthetic fuel (hydrogen) and coal gas and coal. - 1 decentralized electric supply system known as: total energy (up to 5 MW output) (diesel generators or gas turbine or fuel cells.) For each supply category, the model needs the knowledge of: - the supply constraint given in units of 10^{15} Btu. - the amount of energy that can be delivered by a particular supply category, limited either by the energy conversion capacity or by the quantity of available energy resources. m=15 demand categories are considered as follows: The demand is divided into 2 sub-categories: - exogenous demand, i.e. different categories of energy demand: space heat, air conditioning, electricity at 3 different load factors, water desalination, pumped storage, production of synthetic fuels, water heating, miscellaneous thermal heating, air transport, ground transport (public and private), iron production, cement production, and petrochemy and synthetic materials. - endogenous demand: for the electricity mentioned above the model takes into account the load duration curve of the system. For certain demand categories, the different plants can be mixed in order to optimize the global load factor curve. The load structures on a seasonal and weekly basis are taken into account.
Ecological	The model incorporates air pollutants and other wastes generated by energy conversion activities that are proportional to the amount of energy delivered: CO_2, CO, SO_2, NO, particulates, hydrocarbon, radioactive wastes and thermal wastes. Other pollutants and land use will be incorporated in the expanded model.
Economic	The coefficients of cost in the objective function reflect the necessary cost of the facilities used in the energy supply system as well as fuel and other operating costs. The necessary cost of capital for the electric supply category is a function of the plant load factor which is also a function of each specific demand category.
Output Data Physical	The model gives for a specified level of each demand the optimal utilization of the different available supply systems.
Economic	The model gives the total cost of the energy system but the resulting optimal path is greatly dependent on the different input costs.
Ecological	The model gives the volume of the different polluting emissions.
Observations	- This model is static; it can be used only for one year. For that year it is necessary to know the demand and the supply categories. The level of the different kinds of demands can be obtained by using an input-output model. - The price electicity of demand is not taken into account in the current model but is being added to the expanded model. - Dynamization of the model is being studied.

Summary reviewed by the author of the model.

MODELS CLASS D

U.S.A.

The Model		W. Nordhaus, 1973[62], Yale University, New Haven, Conn. Allocation of Energy Resources.
Subject and Goal		The author discusses the efficiency of market forces to determine the prices of energy resources, using the framework of the theory of general equilibrium. He then proposes a model to determine the efficient allocation of energy resources over time.
System Described		The energy system of the free market world on a very aggregated level. The resource variables are petroleum, oil shale, coal, nuclear fuel, natural gas. The demand is broken down into electricity, process heat, residential heat, substitutable transport, non-substitutable transport. In the supply mining model many different technologies are involved: refining, coal gasification and liquefaction, breeder reactors, electric automobile, hydrogen fueled automobile, etc. The author introduces the concept of backstop technology--a set of processes which i) can meet the demand requirements and ii) have virtually an infinite resource base. This permits him to avoid the fixing of a horizon.
Area	Time	1970 to infinite, broken down into 9 time periods: 1970, 1980, 1990, 2000, 2010, 2020, 2045, 2070, 2120 to infinite.
	Space	Free market world broken down into 5 regions: USA, Japan, Western Europe, Persian Gulf and North Africa, and the rest of the world.
Modelling Techniques		Linear programming and sensitivity analysis. Given demands, resource availabilities and technologies, the model calculates the optimal path that minimizes the costs of meeting the demand. The demand side assumes that there is no responsiveness of final demand to price, and that fuels are perfectly substitutable for meeting demand requirements.
Input Data Physical		Resource availability for recoverable energy resources. The different sector demands for each region and each period.
Economic		Costs of extraction, transportation and processing for each fuel in each region. Rate of interest. The paper describes in detail how these data are constructed.
Output Data		- The optimal path, i.e. for each period, each region and each sector demand, the set of fuels and processing technologies. - The shadow prices of scarce resources, which can be interpreted as rent or royalty. The fuel prices are the sum of shadow prices and of costs of extraction.
Observations		The linearity of the objective function, the inelasticity of the demand and the lack of linkage with the rest of the economy, the assumption of free trade and the high level of aggregation are oversimplifications. Nevertheless the model permits the author to develop interesting comments on the present evolution of our energy system. He also gives conclusions about the implications for energy policy, e.g. evaluation of the costs of an autarky policy for the U.S.

Summary not reviewed by the author of the model.

MODELS CLASS E

AUSTRIA

The Model		J. Richter and W. Teufelsbauer, 1973 (63), Bundeskammer der gewerblichen Wirtschaft, Vienna. Austria II.
Subject and Goal		AUSTRIA II is an iteratively solved, demand-oriented input-output model (medium term, constant prices, 31 sectors, 11 components of final demand, distinction between competitive and non-competitive imports). Technological change and development of foreign trade partners are exogenous. With respect to energy, "crude oil extraction and refinery" and "electricity, gas and water" are treated as separate sectors; "coal mining" will be a separate sector in the next stage of the model. AUSTRIA II's main purpose is to serve as a tool for management information by simulating alternatives of foreign trade developments and technological change, and by investigating the effects of bottlenecks of raw material imports.
System Described		The model describes the levels of 31 categories of production and various kinds of non-competitive imports required to meet a given bill of final demand with the help of an input-output model (changes in the technological structure are introduced exogenously). The components of final demand (31 categories of private consumption, etc.) are determined by variables such as foreign demand, disposable income, GNP, the parameters of the consumption functions, investment functions etc. are estimated by means of time series analysis. Imports of goods where there is no domestic production (cotton, rubber) or one with fixed capacity limits (crude oil, coal) are determined by the levels of output of those industries to which these imports are inputs.
Area	Time	So far annual forecasts have been made up to 1980.
	Space	Austria.
Modelling Techniques		Iteratively solved input-output model.
Input Data		Austrian input-output table for 1970 (31 x 31), which was estimated by updating the official 1964 table (54 x 54). This work was done in cooperation with the Österreichisches Institut für Wirtschaftsforschung. Time series for final demand components and categories in real terms, some time series on technical coefficients: - Investment plans of enterprises; - Investment plans of the public sector; - Engineering information on technological change.
Output Data		For a given scenario (foreign demand, technological change, etc.) the model provides for each year up to 1980 an input-output table (31 x 31) in constant prices.

Summary supplied by the author of the model.

FRANCE

The Model	D. Blain, 1972 (64), Ministère de l'Economie et des Finances, Paris. FINER, Energy Financing Model.
Subject and Goal	The model shows the middle to long term economic and financial consequences of various energy policies on pricing, taxes, investments, requirements, regulations.
System Described	The model describes the set of energy production and consumption processes in the sectors of industry, transportation, siderurgy and household and commercial. It takes into account interfuel competition and optimizes the tools of production for a given consumption.
Area — Time	1970 to 1985 or 1990.
Area — Space	France as a whole.
Modelling Techniques	Simulation model using econometric equations and embedding results of partial optimization for different kinds of energy (e.g. electricity).
Input Data Macroeconomic	- main variables describing French economic growth - growth rate of GNP, household consumption - general indexes of prices and salaries - number of new lodgings - rate of interest
Sectoral	- national production of coal and distilled fuel oils - price of imported energy (crude oil, gas, coal, uranium) - energy prices at consumer level - different taxes on energy - description of the national and international financial market - financial constraints for the different utilities - official regulation of energy use.
Output Data Physical	For each year: - annual consumption for each kind of fuel for each demand sector - energy imports
Economic	- operating costs and financial requirements for the big national utilities (electricity, gas, coal) and for the oil sector. The model also gives the impact of the energy producing sector on the rest of the economy: - financial balance - employment - incremental investment - financial market - budget expenditures.
Observations	The FINER model allows the assessment of all the possible energy policies. The equations are derived from econometric studies implemented during 1950 - 1970. In particular this study is concerned with consumer behavior and utility management. Some structural modifications can be introduced by using slack variables.

Summary supplied (in French) by the author of the model.

IRELAND

The Model		E. W. Henry and S. Scott, 1973 [65], Economic & Social Research Institute, Dublin. Price Increase of Imported Fuels.
Subject and Goal		To calculate the effect on sectoral prices of a rise in the price of imported fuels, especially oil, given certain assumptions.
System Described		The model covers 33 sectors of the economy in an input-output framework.
Area	Time	Static model; calculates the effects of fuel price rises in 1973/74.
	Space	Ireland.
Modelling Techniques		Input-output price model.
Input Data		The 33-sector 1968 input-output table for Ireland was disaggregated to give more detail: an oil refining sector was constructed, transport was disaggregated into 5 types, and imports were broken down to give details of different fuel imports.
Output Data		For any level of price rise of imported fuel, sectoral prices are given as well as the new costs of final demands, e.g. the new cost of living, etc.
Observations		This model can account only for the rises in price resulting from rises in costs and cannot take into consideration "demand-pull" type price rises.

Summary supplied by the author of the model.

The Model		Keichi Oshima, 1974 (66), Industrial Research Institute, Tokyo. Energy Utilization in the Future.
Subject and Goal		A simulation model for assessing the macrodynamics of the energy system in Japan, in particular the impacts of the increase in crude oil price, and of more stringent regulations on environmental pollution, on the national energy system.
System Described		The system is divided into three sub-systems; the sub-system for estimating economic growth in the future; the sub-system for estimating energy cost based upon energy demand in accordance with economic growth and upon energy supply available; the sub-system for estimating the retrictions on pollution caused by energy consumption.
Area	Time	From 1975 to 2000.
	Space	Japan as a whole.
Modelling Techniques		Simulation model using systems dynamics. The size of the model is as follows: 9 main variables, 16 growth rate variables and 24 auxiliary variables. Involved in the model are the following 5 feedback loops of flow. 1) positive feedback loop of economic growth: economic growth - capital stock - productive capacity - economic growth - ... 2) negative feedback loop of energy cost (energy demand by industry): productive capacity - energy demand by industry - total energy demand - balance between demand and supply - energy cost - productive capacity - ... 3) negative feedback loop of energy cost (domestic energy demand): economic growth - national income - energy demand (domestic) - total energy demand - balance between demand and supply - energy cost - productive capacity - economic growth - ... 4) negative feedback loop of preventive measures against pollution (technical aspect): released pollutants - regulation and/or inhabitants' reaction against pollution - preventive measures - released pollutants - ... 5) negative feedback loop of preventive measures against pollution (economic aspect): energy consumption - released pollutants (loop 4) - preventive measures - capital stock (loops 1, 2 and 3) - total energy demand - energy consumption - ...
Input Data		The relationship between variables is given in the form of tables; e.g. the rate of economic growth is represented by the linear combination of the rates of capital stock increase and of working population increase. The coefficients are obtained by regression analysis from the statistical data in Japan for the past 10 years. Almost all these data are built into the model, but there are some unknown parameters which must be fixed according to the purpose of each calculation: price of crude oil, quantity of imported oil, level of energy reserve, technical efficiency of preventive measures against pollution and ameliorability of preventive measures resulting from inhabitants' reaction against pollution - .
Output Data		Every variable can be displayed as an output and therefore it should be selected in accordance with the purpose of each calculation.
Observations		This model is a macromodel since it has only two sectors of energy demand, i.e. industry and household. This makes it impossible to assess the allocation of energy to individual industrial sectors. An extended model is due to be constructed.

Summary not reviewed by the author of the model.

JAPAN

The Model		Institute of Energy Economics, Tokyo, 1973[(67)]. Optimizing Energy Allocation to Industrial Sectors.
Subject and Goal		When the level of total energy demand is given, the optimal allocation of energy is calculated by this model for the target function minimizing SO_2 pollutant and energy supply costs.
System Described		The system consists of an I/O table of 22 sectors, e.g. oil refinery industry structure, demand sectors of oil products and final demand sector. The optimal allocation and selection of energy (especially oil products and their alternatives) is calculated by LP methods.
Area	Time	Single year.
	Space	Japan as a whole.
Modelling Techniques		A simulation model for input-output analysis connected with the linear programming method. The size of the model is: 168 LP rows, 513 non-slack variables, 1,690 LP elements, density 1.96%. - Objective function: minimization of crude oil cost (imported material cost + refining-cost + desulfurizing cost) - General industrial sector: 22 subsectors forming a normal input-output table, production activity based on the given final demand level - Oil refining sector: described as an oil refinery which produces all oil products from motor gasoline to heavy fuel oil. The refinery has 4 kinds of producing equipment and 5 types of desulfurization plant - Demand for oil products: light and medium distillates are consumed directly in each industrial sector, but fuel oils (mainly heavy fuel oil) are selected in accordance with their sulfur content; i.e. each sector can freely select better quality fuel to satisfy environmental standards - Final demand: the aggregate of expenditure and non-housing consumption, private consumption, government expenditure, domestic fixed capital formation, excluding inventory and exporting.
Input Data		- Level of final demand in the estimated year. - Costs and availability of imported crude oil. - Costs and availability of imported LNG and oil products. - Fixed and operating costs, and capacity of desulfurization equipment. - Environmental standard in the estimated year: amount of sulfur pollutant. - Input coefficients of each general industrial sector in the I/O table. - Other coefficients.
Output Data		Level of consumption of oil products selected in individual sectors; desulfurization capacity; quantity and quality of imported oil and oil products, and shadow prices.
Observations		This model is connected with the model for assessing long-term energy demand. Its extension and modification are under way.

Summary supplied by the author of the model.

JAPAN

The Model		Institute of Energy Economics, Tokyo, 1973[68]. Long-Term Energy Demand in Japan.
Subject and Goal		This model is concerned with estimating the level of gross energy demand and its distribution among economic sectors. The level is determined by such factors as the growth rate of economic activity, the industrial structure and evaluation of industrial processes, and energy supply conditions.
System Described		The system is divided into 3 subsystems: the economic sector, the energy demand and supply sector, and the environment sector. The subsystems are linked via the system dynamics method.
Area	Time	From 1970 to 2000.
	Space	Japan as a whole.
Modelling Techniques		System dynamics model including I/O analysis. The size of the model is as follows: 7 variables for levels, 10 variables for rates and 64 auxiliary variables. The following 3 feedback loops are involved in the model: - negative feedback loop of economic growth due to the constraint on energy supply - rate of private investment - GNP - energy demand - energy shortage gap - rate of private investment. - positive feedback loop of economic growth caused by the investment for desulfurization. GNP - energy consumption - SO_2 pollutant - investment for desulfurization - total investment for pollution - GNP. - negative feedback loop of SO_2 pollutant due to the desulfurization process. Released pollutant - standard of air pollution regulation - environmental gap - investment for desulfurization - capacity of desulfurization facilities - energy consumption - released pollutant. The industry is divided into four sectors, agriculture, heavy industry, light industry and service industry. Energy demands in four industrial sectors and household sectors are calculated using I/O techniques. The evolution of the industrial process is systematically expressed.
Input Data		
Economic		Main exogenous variables: reference rate of private investment growth; ratio of public investment/private investment; I/O coefficients.
Energy		Unit of energy consumption, availability of import oil, alternative source of energy.
Environment		Average S content in import oil. Environmental standard.
Output Data		Typical output data: real GNP and economic structure; total energy consumption; oil consumption; investment for desulfurization facilities; SO_2 pollutant.
Economic		Growth rate of economy, final demands and products of 4 industrial sectors, composition rate of 4 industrial sectors.
Energy		Energy demands for household and different industrial subsectors; stock pile.
Environment		SO_2 pollutant, investment for desulfurization.
Observations		This model is useful for simulating the relationship between energy supply and the macroeconomic structure, but cannot assess the effect of an energy price increase on the national economy. An I/O-LP model with this aim is under development by the Institute.

Summary supplied by the author of the model.

SWEDEN

The Model		B. O. Karlsson, 1973[69], Ministry of Finance, Stockholm. SVEN - Swedish Economy 1970-1977.
Subject and Goal		To indicate the total effect upon production, employment, foreign trade, etc., generated by different kinds of disturbances in the supply of energy goods. To calculate the minimum level of energy input required to reach certain goals of economic policy, such as employment.
System Described		The model (SVEN) is a variation of the econometric model used in the revision of the 1970 medium-term survey. It shows how disturbances in the supply of energy goods influence the economy as a whole and the various branches of industry and trade, and whether gains could be made by redistribution of energy products, e.g. in the level of employment. Since, however, the model is adapted from a macroeconomic model constructed for other purposes, its power of analysis is rather limited. In particular all variables (except employment) are expressed at 1968 market values.
Area	Time	Static model for a particular point in time.
	Space	Sweden.
Modelling Techniques Input Data Output Data		The basic model from which this model is derived describes the development in 24 production sectors, distinguishing between public authorities and other parts of the economy; consumption and production in the public sector are determined exogenously. Also gross investments, changes in stocks, development of productivity and total labour supply are exogenous variables. Using this information the model computes for the different sectors the development of production and employment, imports, exports and private consumption, subject to the general conditions of macroeconomic balance (including a balance of payments restriction) and full employment. The core of the model is a set of input-output matrices which describes delivery flows between the sectors of the economy. The coefficients of those matrices are projected into the future, in principle by using the historical trends but subject to certain restrictions and including possible exogenous information. Other important components are a set of import functions to explain how the development of imports is influenced by different categories of demand, and a group of consumption functions to describe demand from the household sector. The scope for private consumption as a whole is determined residually in the basic model. The energy model (SVEN), developed from the basic model, is an optimization model with either the employment level or the energy supply as objective function. Possible substitutions and energy savings are led into the model on the basis of exogenous information. As a rule certain constraints are impressed on the levels of consumption.
Observations		The model is designed to describe some structural features of economic development and is thus not intended for short-term forecasting. It is simultaneously determined. In a version SVEN 2 the energy model has been extended into 32 sectors. The disaggregation implies that 7 specific energy sectors (heating oils, petrol hydroelectric power, thermal power, gas manufacture and distribution, steam and hot water supply and water works and supply) and 3 sectors dependent on oil products (asphalt and lubricant, plastics industry and other chemical industry) have been accounted for separately.

Summary supplied by the author of the model.

U.K. - U.S.A.

The Model	F. G. Adams and P. Miovic, 1968(70), University of Pennsylvania, Philadelphia, Pa.; L. G. Brookes, 1971-1972(71,72,73), U.K. Atomic Energy Authority, Harwell, Didcot, Berks. Tradeoff Between Energy and GNP.
Subject and Goal	The forecasting of energy demand using a model of the relationship between useful energy consumption and GNP.
System Described	The model simulates an adopted theoretical relationship between useful energy consumption per capita and GNP per capita. Inputs of GNP per capita produce outputs in the form of estimates of useful energy consumption per capita.
Modelling Techniques	Three hypotheses were adopted: - that a high level of GNP per capita implies a high level of energy consumption per unit of output and vice versa - that the useful energy coefficient (GNP elasticity of useful energy consumption) falls from infinity to 1 as a country passes through the various stages of economic development - that contemporary cross-section studies of different countries in different stages of economic development, because they exclude time-dependent effects, produce results that reflect the fundamental relationship between useful energy and GNP, and not, for example, the effects of substitution of one fuel for another or the differing economic efficiencies of the different fuels. The following relationship between useful energy per capita (E) and GNP per capita (G) is postulated (Brookes): $E = AGf(G)$ where A is a constant and $f(G)$ is a saturating function tending to 1 as G tends to infinity. Parameters of this function are computed by fitting cross-section data on energy per capita and GNP per capita for 22 countries ranging in economic development from Pakistan to the U.S.A. 16 cross-sections for the years 1950 to 1965 were taken to establish the stability of the postulated relationship. The method was further tested by comparing model predictions with through-time data for U.K. and U.S.A. (1946-1970) using usefulness coefficients derived by Adams and Miovic to convert primary energy statistics into useful energy.
Input Data	For the derivation of the model: - cross section data of the different fuels used by a group of countries of different economic development - similar cross-sections of deflated GNP - population data, to determine per capita energy consumption and per capita GNP in constant dollars. For national and regional forecasts: - time series of fuel consumption, population and deflated GNP - usefulness coefficients to convert fuel consumption into consumption of useful energy.
Output Data	For the derivation of the model: - a mathematical function linking GNP per capita with useful energy consumption per capita. For forecasting: - estimates of useful energy consumption given estimates of GNP and population.
Observations	This model has been used for both national and world forecasts of energy consumption up to the year 2030.

Summary supplied by one of the authors of the model.

U.S.A.

The Model		Robert A. Herendeen, 1973[74], Oak Ridge National Laboratory, Oak Ridge, Tenn. Use of I/O Matrix.
Subject and Goal		This model quantifies in physical units the total (direct and indirect) energy demand resulting from the production and marketing of various goods and services. The model is used to obtain a detailed breakdown of the energy used to make a consumer product. Three examples of application are given: - Calculation of the total energy used for the production of the private automobile in 1963 - A calculation of the efficiency of the energy sector in providing energy to final demand - A calculation of the energy cost of a kitchen electric mixer.
System Described		The economic system is described by the input-output framework of the Bureau of Economic Analysis (B.E.A.) of the US Dept. of Commerce. This framework consists of a 362-sector technological coefficients matrix. Five of these are energy sectors: coal, crude oil and gas extraction, refined oil, electricity, and gas sales.
Area	Time	This static model is based on 1963 data. An attempt is made to make it usable for 1960 and 1970.
	Space	U.S.A. as a whole.
Modelling Techniques		Transformation of an Input-Output (I/O) model A transformation is used to convert the 1963 I/O results (from B.E.A.), which are in terms of dollar sales, into energy terms. The author uses statistics of energy sales to consumption sectors to calculate relevant energy price indexes. This permits him to build total energy coefficients, e.g. which give the total output of the different energy sectors required for the economy to deliver a dollar's worth of a given product j to final demand. The basic equation of the model is: $\underline{\underline{E}} = [\underline{\underline{R}} (\underline{\underline{I}} - \underline{\underline{A}})^{-1} + \underline{\underline{S}}] \underline{Y}$ or $\underline{\underline{E}} = \underline{\underline{\epsilon}} \underline{Y}$ where E_i = total energy output of energy- producing sector i; $\underline{\underline{A}}$ = technological coefficients matrix; $\underline{Y}$ = final demand vector; $R_{ij} = \frac{1}{p_{ij}} A_{ij}$, where p_{ij} is the price of energy i sold to sector j; $S_{ij} = \begin{cases} \frac{1}{p_i}, & \text{if } i = j = \text{energy sector} \\ 0 & \text{otherwise.} \end{cases}$ Using the total dollar coefficients $(I - A)^{-1}$ the author calculates the dollar demand of each sector resulting from a dollar's final demand of sector j, and uses the direct coefficient (A) and price (p) to determine the energy used by each sector to meet that requirement for its output. Summing gives the total energy requirement.
Input Data		(367 by 367) sector I/O model; (5 by 362) price indexes matrix.
Output Data		- (5 by 362) total energy coefficients matrix. - Also provided are breakdowns of total energy requirements by sectors for production of appliances made from purchased material: household refrigerators and freezers, motor vehicles and parts. - Other case studies calculate the energy impact of the automobile in 1963 and the total primary energy required to deliver 1 BTU of energy of various types to final demand (for each energy producing sector).
Observations		- Because the B.E.A. I/O table is based on the industrial establishments and not on the products, corrections are necessary. - To assure that there are no losses between primary and secondary energy sectors, a reallocation method to final demand has been used. In further work, the author will study the problem of capital goods not for the moment listed as sales to final demand (this leads to underestimating the total energy coefficients). It would be interesting also to convert final demand measured in purchaser's prices.

Summary not reviewed by the author of the model.

U.S.A.

The Model	James E. Just, 1973[75], Massachusetts Institute of Technology, Cambridge, Mass. Energy Analysis Using I/O Matrix .
Subject and Goal	- Forecasting of impacts of new energy technology, e.g. high and low BTU coal gasification, gas turbine topping cycle. - Development of a general tool for technology assessment.
System Described	Mainly the economic system enlarged by some environmental and resource aspects which are linked to the usual economic variables.
Area — Time	1980 - 1985.
Area — Space	U.S.A. as a whole.
Modelling Techniques	Standard I/O model. Generalized two-period "dynamic" I/O model. The U.S. economy is represented by an I/O structure (104 sectors). Each new energy technology is characterized by a vector of technical coefficients, a vector of capital coefficients, a vector of accessory coefficients (i.e. all non-economic impacts which can be assumed as proportional to final outputs). The I/O model is used to compute: - the economic impact of capital expenditures for new technologies - the impact from actual operation of new plants using these technologies - the price changes caused by a rise in cost of energy. The two-period I/O model, through an iterative process, affords a series of 1985 projections that illustrate various economic impacts of energy use growth and technological change. 5 scenarios are built: - low, medium and high energy use growth rate - high energy use growth rate with coal gasification - high energy use growth rate with coal gasification and gas turbine topping cycle.
Input Data Physical	104 x 5 energy use coefficients; 104 x 5 steel use coefficients.
Economical	104 x 6 final demand vectors for 1963, 1970, 1980 (104 by 104) technological coefficients matrix for 1963, 1970, 1980 (104 by 104) capital coefficients matrix for 1963, 1970, 1980 104 employment coefficients.
	In the 1985 projection GNP = 1.34×10^9 \$ at 1958 constant dollars. Growth rate of non-investment energy-related final demand over the 1980-1985 period.
Ecological	104 x 5 air pollution coefficients.
Output Data Physical	Energy use by fuel type: coal, crude petroleum, refined petroleum, natural gas, electricity.
Economical	Total output by sectors (104); employment; 1985 projection of final demand.
Ecological	- Air pollution emissions: SO_2, CO, NO_x, particulates, hydrocarbons - Gross water usage - Cooling water usage.
Observations	The model is quasi-static and linear. The consumer representation is weak (elasticities). The disaggregation of the energy industries is insufficient; progress could be obtained by: - more bench-mark projections or dynamization - more accurate regionalization of industrial energy usage.

Summary not reviewed by the author of the model.

U.S.A.

The Model		R. J. Rahn, 1973(76), Dartmouth College, Hanover, N. H. Dynamic Model of Energy and Economic Growth.
Subject and Goal		The purpose of the model is to describe the long-term interaction of determinants of energy supply and demand in the US economy. The main questions were: what is the most likely pattern of the total energy consumption during the transition from fossil fuels to ultimate energy sources, and what is the role of domestic coal reserves as a transition fuel source? The model is not a forecasting tool; its aim is to project possible behavioral modes of total energy consumption over the next 30-50 years, and to test several policies for their effects upon the transition process.
System Described		The model is based on the following 5 assumptions: - Domestic resources of coal, oil and natural gas which cover major energy requirements - Ultimate energy sources essentially independent of depletable fuel resources are developed and used after the price of fossil fuels rises - The indicated energy consumption; the amount of energy the economy would consume at current prices is a function of population and income as measured by industrial output per capita - Economic growth is described by a modified Harrod-Domar capital-growth model - Restrictions on energy production capacity due to fossil fuel depletion or delays in developing ultimate sources may reduce the economic output. The basic structure of the model is given by 4 feedback loops describing the interrelationship between the main variables of the model: energy requirements, fossil fuel resources, production capacity of fossil fuel energy industries, production capacity of ultimate energy sources, average energy price, production capacity per unit of capita, industrial output and population. The model explicitly takes into account only 2 energy sources, the ultimate energy sources and the domestic fossil fuel resources, which are an aggregation of the domestic oil, natural gas and coal resources.
Area	Time	The time horizon extends from 1950 to 2050 since the time necessary for a complete change of capital and technology in energy industries takes of the order 30-50 years.
	Space	U.S. as a whole.
Modelling Techniques		Feedback loops are the basic structural elements. The system dynamic approach is used to describe the interrelationships between the elements of the model.
Input Data		The initial values of the levels of e.g. population, fossil fuel resources, industrial capital, ultimate source energy capital, fossil fuel energy capital, and the relationships between certain variables of the model which are described by table functions, e.g. indicated energy consumption per capita from the energy price.
Output Data		The output describes the dynamic behavior of the system variables corresponding to the different policies to be tested.
Observations		The model - excludes explicit consideration of the issues surrounding energy imports - aggregates the domestic fossil fuels into one resource, so that substitution between petroleum, natural gas and coal can not be studied - ignores the dynamics of intersectoral and inter-fuel demand and supply - does not take environmental problems into account - is very sensitive to changes in the basic growth parameters, availability of fossil fuel resources, cost of ultimate source developments, delays in reading the economic signals of increasing resource scarcity and in acquiring ultimate energy source capacity.

Summary not reviewed by the author of the model.

U.S.A.

The Model		P. K. Verleger, 1973[77], Data Resources, Inc., Lexington, Mass. Relationship Between Macroeconomic Activity and Energy Consumption.
Subject and Goal		This model is part of a more general one as follows: - An aggregate supply-demand econometric model of the U.S. economy which incorporates the flows of labor, capital, energy, etc. This model is still in the development stage and discussed here. - A model referred to as an energy balance model, which provides a framework for the analysis of energy supply, demand, and prices, given a projection of economic activity.
System Described		The energy balance model is divided into 3 sectors: - a set of bridge equations used to relate demands by the economy for energy to physical demands - a set of energy production functions that translate these demands into fuel requirements - a set of physical supply functions for fuels. Only the first 2 parts are discussed; the 3rd is still being developed.
Area	Time	Historical simulation from 1948-1971; projection to 1980.
	Space	U.S. as a whole.
Modelling Techniques		The energy demand supply equations are econometric equations. For the demand, the author uses relations developed by Houthakker and Taylor: per capita consumption is explained in terms of relative prices and per capita personal consumption expenditure (with lagged variables). The supply equations so far only involve the electric utility sector. The equations are fitted by multilinear regression analysis.
Input Data		Demand: - per capita consumption expenditures - relative price of energy (measured as the ratio of the deflator for energy consumption to the deflator for total consumption) - implicit deflator for consumption of electricity and natural gas. Supply: - household, industrial and transportation electrical consumption - transmission loss - nuclear investments - fuel price and price of the minimum cost fuel (natural gas) - dummy variables.
Output Data		Energy consumption in the household commercial sector: - consumption of energy per capita - consumption of electricity, natural gas and petroleum products - consumption of coal (explained by extrapolation) - short and long run income elasticity, price elasticity. Electricity supply calculated from the demand and transmission loss minus imports by trend extrapolation: - output from nuclear generation sources and hydro-production - production by fossil fuel generation - shares of the different types of fossil fuel, obtained by considering the share of fuel f's generation relative to the generating capacity share of fuel f $(Q_f/Q)/(K_f/K)$ = F(prices of f, price of the minimum cost fuel).
Observations		These models of supply and demand are incomplete and preliminary; numerous improvements are planned. A large part of this paper is devoted to presenting the author's ideas on to the construction of a general energy model intended to link the energy sector with the economy as a whole.

MODELS CLASS F

F.R.G.

The Model		A. Voss, 1973[78], Kernforschungsanlage Jülich. Analysis of the System Man-Energy-Environment.
Subject and Goal		The model is an approach to an overall analysis of the system man-energy-environment and considers economic, ecological and technological aspects. It has been developed to show possibilities of a long term development of the world's energy system, particularly with respect to embedding, and aims at a quantative description of alternative energy supply strategies by evaluating the positive and negative effects of satisfying energy demand and providing its supply systems. The description of substitution mechanisms between primary energy sources is emphasized.
System Described		The interactions between the energy system and the environment are described in 5 sectors: population sector, energy sector, non-renewable resource sector, industrial production sector, pollution sector. The development within the interactions between sectors determines the development of the overall system and thus that of energy demand. Besides the effects of energy consumption and exploration of new energy resources, the energy sector of the model describes substitution among primary energy sources. For the representation of substitution dynamics a differential equation statement is used, whereas time-variable causal factors of substitution (energy costs, availability, characteristics of use) are described by a utility function.
Area	Time	The time horizon is from 1900 to 2100.
	Space	It is a world model; no regional disaggregation.
Modelling Techniques		The model uses simulation techniques. The dynamic interactions and the feedback loops are described by the system dynamics approach (developed by J.W. Forrester).
Input Data		As the model is a closed cybernetic simulation model, the initial values of the state variables and certain functional relationships must be described. Some of the most important functions are: - birth and death rates vs. material standard of living - primary energy production costs vs. cumulative primary energy consumption - energy consumption per capita vs. material standard of living - reduction of environmental burdens vs. cost requirement.
Output Data		The development in time of variables such as population, energy consumption, energy reserves, shares of individual energy carriers in the energy supply, industrial production environmental burdens, raw material consumption.
Observations		The model is a strategy rather than a forecast model. It shows a high degree of aggregation and uses global averages. Studies on the disaggregation is space and the differentiation of the environment sector are under way.

Summary supplied by the author of the model.

The Model		International Study Group on the LINK System (L.R. Klein, University of Pennsylvania, Philadelphia, Pa.), 1973 (79). International Linkage of National Economic Models.
Subject and Goal		The LINK system was developed for forecasting and policy analysis in world trade. It has been used to estimate some international multipliers to study effects of alternative national policies, and to simulate various exchange rate configurations.
System Described		The LINK system consists of separate models for 13 countries (developed and developing), regional models for 4 developing areas, and some equations in reduced form for 12 developed countries.
Area	Time	LINK calculations can be made at various time during the year. If there are meaningful exogenous inputs for the separate models it is possible to obtain reasonable model solutions over multi-year horizons.
	Space	Whole world trade system.
Modelling Techniques		The LINK algorithm works as follows: <u>Step 1</u>: Each national model makes a best estimate of local inputs and submits that for a control solution to LINK Control. <u>Step 2</u>: All national models with the inputs needed for solution are loaded in the LINK computer file. <u>Step 3</u>: Import and export prices of products for each national model are converted to merchandise only, FOB valuation, into current U.S. $. <u>Step 4</u>: Exports are computed from a trade share matrix multiplied into the computed vector and adjusted for price effects as in the equation below: X 73 $ = A . M 73 $ where: X 73 $ is exports in 1973 US Dollars M 73 $ is imports in 1973 US Dollars A is the trade share matrix. <u>Step 5</u>: Import prices of each country are re-evaluated from column weighted sums of changes in computed export prices of the other countries. <u>Step 6</u>: National models are successively resolved with new input values for export and import prices determined in steps 4 and 5. <u>Step 7</u>: Steps 3-6 are repeated with new solution values and re-iterated until the total volume of world imports in current $ no longer change on successive iterations.
Input Data		Exchange rates, FOB/CIF ratios, portion of goods and services, depending on unit used in national models; import and export quantities and prices of the various national models.
Output Data		Inflation rates, growth rates, export bills, import bills for each country in the LINK system.
Observations		The LINK system can be very useful for world energy modelling.

Summary not reviewed by the author of the model.

The Model	M. Mesarovic, 1974 (80), Case Western Reserve University, Cleveland, Ohio, U.S.A., E. Pestel, Technische Universität Hannover, F.R.G. Energy Models of the Multilevel World Model Project.
Subject and Goal	Only the energy sub-model of the multilevel world model is summarized here. It is divided into 3 sub-models: energy resource model, the demand model, the energy supply model. These sub-models are to be connected with the sub-models studying the population, economy and environmental systems. The main goal of this model is not to forecast but to aid in decision-making and serve as a tool for building scenarios.
System Described	The world is divided into 10 regions. The first model estimates the regional and global primary energy resources and simulates the energy resource exploitation in order to look at the impact of extraction rates and recovery factor on reserves. The second model estimates regional primary energy demand, using 2 approaches. One is specific by region, for each of which 7 types of relationship are analyzed. The second is a "generic approach", wherein the authors try to find general laws. They use the same basic relationships but the respective coefficients were considered as functions of changes in the level of economic development. The third model presents a detailed simulation for energy supply. It traces the energy flow from primary input through conversion to secondary energy and finally to distribution to the user. It also computes energy and investment costs and wasted energies. At this time this sub-model gives results only for the U.S., Western Europe and the Middle East.
Area – Time	Horizon 2025 (past data used are taken in the time period 1950-1965).
Area – Space	World divided into 10 regions: North America, Western Europe, Japan, rest of developed Eastern Europe, Latin America, Middle East, Main Africa, South East Asia, China.
Modelling Techniques	The 3 models are not directly connected at present. Linkage has so far been off-line: the time series output of one model (e.g. energy demand) has been used as input for another (e.g. energy supply model). Resource Model, divided into 2 studies: - a statistical effort to compile the level of the different reserves of raw material. The authors adopted the terminology of McKelvey ["Mineral Resource Estimates and Public Policy" - American Scientist - Jan. - Feb. 1972], who distinguishes the levels of reserves according to the degree of certainty and the feasibility of recovery - a simulation of the exploitation of raw materials, considering the factors influencing the supply: production rate and impact of new technologies of exploitation. Demand Model: 7 plausible relationships are made and tested against available past data; 4 are linear functions between energy and gross regional product (GRP), 3 use the elasticity between energy and GRP. The linear or the elasticity coefficients are either functions of time or constants. Note that only the total energy consumption is studied in this sub-model, and the prices are not directly taken into account. All coefficients are calculated through regression techniques. Two approaches are investigated: one specific for each region, and another which takes the stage of economic development as a parameter, so that the relationship between energy consumption and GRP can be used for any region. Supply Model: also a simulation model for detailed planning of a regional energy system from primary energy inputs to secondary distribution to the final user. The structure consists of a network of elementary allocation, and conversion processes. 13 primary and 7 secondary energy forms are considered; 27 conversion processes are incorporated.
Input Data	Resource Model: statistics on raw materials classified by degree of certainty and feasibility of economic recovery; extraction rates and recovery factor. Demand Model: past time series of the volumes of global energy consumption and gross regional products. Supply Model: - physical parameters necessary to describe the flows of energy in each branch of the network representing the energy system from supplier to user: e.g. net primary input, conversion efficiencies, distribution fractions by form of energy to the users, user sector efficiencies. - investment and management costs in relation to each installation, and all primary energy prices. The model also needs knowledge and the description of the scenarios that the decision-maker wants to simulate. Some proposals are made in the model to help the decision-maker to describe the different kinds of scenario. The running of a simulation requires a careful pragmatic preparation of "scenarios" prescribing each of the parameters over the time period in question (1970 to 2025).
Output Data	The program provides 17 pages of output. The main outputs are: net primary input energies, number of plants of each input kind, secondary energy by user sector, global annual expenditures of the system, capital investment per year.
Observations	The model is still developing; only some test runs have been made. No real linkage between the different sub-models works.

Summary not reviewed by the authors of the model.

Commission des Communautés Européenes

The Model		R. de Baw and F. Van Scheepen, 1973[81], Commission des Communautés Européenes, Bruxelles. Integrated Energy Models for the CEE.
Subject and Goal		The model tries to answer the following questions: - What effect would an increase in the primary energy price have on the economy and the consumption of energy? - Which sectors would be most affected by the increase? - What would be the effect of a temporary interruption in the energy supply? - What measures would have to be taken to limit domestic production? The authors are not looking for a solution geared to these questions, but analyze the mechanisms and behavior of the system and its bottle-necks.
System Described		The model consists of 2 modules (linked by an exchange of information): energy sector and mass of economy. The first module treats the supply and transformation of primary energy; the second consists essentially of an I/O matrix which in its disaggregated form has 90 branches.
Area	Time	Short term; could be used, at a later date, for long term.
	Space	E.E.C. (9 nations).
Modelling Techniques		The supply model is a simulation model which permits evaluation of different solutions. 3 forms of primary energy are considered: coal, oil, and gas. Hydraulic energy and nuclear energy are assumed to be exogenous in the short term. The constraints are the following: available production; means of transportation (especially transportation within E.E.C.); installation of transformation (refinery); production of electricity. In the economy model, the relations between I/O matrix and the energy sector are made via two sub-models: - sub-model of external trade, indicating modifications of the E.E.C. position in the world environment - sub-model of household consumption, giving the quantity of the consumed products as a function of income and prices.
Input Data		- Quantity of the maximum available energy, instead of production. - Capacity of a ship of a given class. - Number of ships in each class. - Capacity of different kinds of transportation. - Transformation of primary energy output into secondary energy. - F.O.B. price of energy and the cost of transportation. - Added value of each sector. - Income and price of products.
Output Data		- Production and its importation of primary energy. - Transformed quantities. - Exportation of different forms of energy. - Reserves of money. - Quantity of household products consumed.
Observations		The two models are not yet completed. It is expected that the supply model will function first, independently of the economy model. Some improvements are planned.

ANNEX I: BIBLIOGRAPHICAL DETAILS OF MODELS

Bibliographical Details of Models

(1) R. Freiberger et al., "Optimization of power system expansion design," Energy Research Institute, Prague, December 1968 (in Czech).

(2) R. Freiberger, "A contribution to optimal indicative long range planning of the expansion of an electric power system over a period of 10-20 years," Proceedings of the Third Power Systems Conference, Paper, Rome, 1969, p. 10.

(3) R. Freiberger, "Modellirovanie razvitiya elektroenergeticheskogo kompleska v dolgsorochoy perspektive - osnovnye problemy i nekotoryi opy," UNO-ECE-EP, Proceedings of the Varna Symposium, Paper A 11, 1970.

(4) R. Freiberger et al., "A multi-node dynamized model of the expansion of resources of an electric power system in the long term prospect," Energy Research Institute, Prague, 1973 (in Czech).

(5) R. Freiberger et al., "Reliability indices in designing an electric power system development--concept and selection of values," Energy Research Institute, Prague, 1973 (in Czech).

(6) P. Kopac and E. Hazuka, "A method of operative prediction of SO_2 and flyash emissions within the framework of the long term development of the energy economy," Energy Research Institute, Prague, 1974 (in Czech).

(7) F. Lidicky et al., "A study of the development trends in the requirements for all forms of energy in territorial distribution for the Czech, the Slovak, and the Czechoslovak Socialist Republic," Energetika, No. 6, 1974 (in Czech).

(8) I. Lencz, "A complex mathematical model of the development of the electric power system," EGU Bulletin No. 5-6, 1969.

(9) I. Lencz, "The planning of power system development with a mathematical model from two points," PSCC, Communication No. P 10/rd, Rome, 1969.

(10) E. Krejcova and S. Pacak, "Méthode éliminatoire pour l'optimisation statique du schéma d'un réseau électrique," Communication pour le Groupe de Travail B1 de la CIGRE, Comité d'Etudes 32, 1969.

(11) E. Krejcova, S. Pacak and V. Zapletal, "Utilisation of an automatic process when determining the scheme of a future network," EGU Bulletin No. 2-3, 1971 (in Czech).

(12) E. Krejcova, S. Pacak and V. Zapletal, "Utilisation des procédés automatiques pour estimer le schéma du réseau futur," Communication pour le Comité d'Etudes 32 de la CIGRE, 1971.

(13) S. Pacak, S. Kriz and V. Zapletal," Study of the development of the transmission system under conditions of high load density," CIGRE Report No. 32-04, 1974 (in Czech).

(14) V. Zapletal and E. Krejcova, "Establishment of a basic scheme of electric networks by means of optimization," Proceedings of the CVTS, Brno, 1973 (in Czech).

(15) E. Rautoma, M. Sourander et al., "Production planning and the new technology," Öljyposti No. 1-2 (Company publication of Neste Oy, Helsinki), 1974 (in Finnish).

(16) J.P. Charpentier, G. Naudet and R. Paillot, "PANACH - Simulation of the nuclear fuel cycle," CEA Rapport économique, Paris, 1973. (The model itself is not available; results appear in the Rapport de la Commission Consultative pour la production d'électricité d'origine nucléaire," Annex VIII, Ministère du Developpement Industriel, Paris, 1973.)

(17) J.C. Dodu, "MEXICO - Modèle probabiliste pour l'étude globale de la sécurité d'alimentation d'un réseau de transport," Electricité de France, Paris, 1970.

(18) J.C. Duperrin and M. Godet, "General presentation of a method for the hierarchical organization of the elements of a system," (MIC-MAC), Commissariat à l'Energie Atomique, Report CEA-R-4541, 1974.

(19) A. Breton, "Application of the theory of optimal control to the choice of production investments at E.D.F.," Electricité de France, 1972.

(20) D. Levi and D. Saumon, "Description of the new model of national investment," Electricité de France, internal note, May 1973.

(21) R. Bieselt, "Wirtschaftlich optimaler Zubau und Einsatz von Kraftwerken in Nordrhein-Westfalen innerhalb eines mittelfristigen Planungszeitraumes von etwa 10 Jahren," Technische Hochschule Aachen, 1972.

(22) W. Meier and A. Voss, "RESTRAPRO - Ein Reaktorstrategieprogramm," Kernforschungsanlage Jülich, 1972.

(23) G. Meurin, "Beitrag zur langfristigen Planung des wirtschaftlichsten Ausbaues und Betriebes eines Kraftwerkverbundes durch integrale Kostenminimierung," Technische Hochschule Aachen, 1972.

(24) H. Tröscher, "General models of electricity utility," paper presented at the 16th International Congress of the International Union of Producers and Distributors of Electrical Energy, The Hague, August 27-31, 1973.

(25) Institute of Energy Economics (M. Sakisaka), "A model for calculating the growth of nuclear power in the future power system," Tokyo, 1973.

(26) M. Bernatowicz, "Multicomponent nuclear power system optimization using integer programming," Conference on Cybernetic Methods in Management, Warsaw, April 22-26, 1974 (in Polish).

(27) J. Podpora, "Influence of various refueling schemes in a two-component nuclear power system," to be published in Atomnaya Energia (in Russian).

(28) W. Frankowski, "Optimization of the composition of a developing nuclear power-plant system under variable load-factor conditions," Atomnaya Energia, Vol. 29, No. 5, November 1970 (in Russian).

(29) W. Frankowski, "Optimization of a system of nuclear power plants at the initial stage of its development," Atomnaya Energia, Vol. 27, No. 5, November 1969 (in Russian).

(30) G. Bergendahl, "A multi-period cost minimization model for Sweden," European Institute for Advanced Studies in Management, WP 74-7, February 1974.

(31) E.S. Ben Salem and M. Höjeberg, "A model for forecasting the future energy supply and demand, subject to alternative assumptions about i.e. oil prices and energy policy," Government Committee for Energy Forecasting, Stockholm, 1973.

(32) Dennis Anderson, "Models for Determining Least-Cost Investments in Electricity Supply", Bell Journal of Economics and Management Science, 3, 1972.

(33) C.E. Iliffe, "A computer simulation of a nuclear generating system," ECE Symposium on Mathematical Models of Sectors of Energy Economy, Alma-Ata, 1973.

(34) F.P. Jenkin, " C.E.G.B. electricity supply models, Part II - A simple electricity supply model," ECE Symposium on Mathematical Models of Sectors of Energy Economy, Alma-Ata, 1973.

(35) H. Houthakker and M. Kennedy, "Demand for energy as a function of price," Harvard University, 1974.

(36) P.W. MacAvoy and R.S. Pyndick, "Alternative regulatory policies for dealing with the natural gas shortage," Bell Journal of Economics and Management Science, Vol. 4, No. 2, Autumn 1973.

(37) Alan S. Manne, "Waiting for the breeder," to be published in the Review of Economic Studies.

(38) W.E. Mooz, "Projecting California's electrical energy demand," in Energy Modeling, Milton F. Searl, ed., Resources for the Future, Washington, D.C. 1973.

(39) I.N. Bessonova, N.S. Kulenow, Z.H. Hasenov, and S.C. Chokin, "Econometric models for energy consumption forecasting," ECE Symposium on Mathematical Models of Sectors of Energy Economy, Alma-Ata, 1973.

(40) A.I. Mekibel and T.M. Polyanskaya, "Models of the power industry sectors: construction and use," ECE Symposium on Mathematical Models of Sectors of Energy Economy, Alma-Ata, 1973.

(41) International Atomic Energy Agency (Team of staff members), "Market survey for nuclear power in developing countries," Vienna, 1973.

(42) Institute of Energy Economics (M. Sakisaka), "A model for the simulation of the future oil flow in the world," Tokyo, 1973.

(43) Energy Research Unit, Queen Mary College (R.J. Deam, M.A. Laughton, J.G. Hale, J.R. Isaacs, J. Leather, F.M. O'Carroll, P.C. Ward), "World energy modelling: concepts and methods," London, 1973.

(44) Energy Research Unit, Queen Mary College (R.J. Deam, M.A. Laughton, J.G. Hale, J.R. Isaacs, J. Leather, F.M. O'Carroll, P.C. Ward), "World energy modelling: the development of Western European oil prices," in Energy Policy, Vol. 1, No. 1, June 1973.

(45) H. Houthakker and M. Kennedy, "The world petroleum model - overview," Harvard University, March 1974.

(46) G. Tintner, "A study of the consequences of a possible energy crisis in Austria," Technische Hochschule, Vienna, 1971.

(47) J.G. Debanné, "A pollution and technology sensitive model for energy supply-distribution studies," in Energy Modeling, Milton F. Searl, ed., Resources for the Future, Washington, D.C., 1973.

(48) Institute for Policy Analysis, University of Toronto (L. Waverman), "Econometric model of energy," Toronto, 1973.

(49) R. Hyndman, "The residential and commercial demand for energy," Institute for Policy Analysis, University of Toronto, 1973.

(50) L. Waverman, "Linear programming transportation models," Institute for Policy Analysis, University of Toronto, 1973.

(51) B. Cabicar et al., "The synthesis and practical verification of the basic structural model of fuel and energy economy," Energy Research Institute, Prague, 1973.

(52) S. Bjørnholm, "Alternative organizations of society in terms of energy use - a Danish case study," University of Copenhagen, 1973.

(53) Zentrum Berlin für Zukunftsforschung (W. Dreger), "ENIS - Energiesektorales Informationssystem," Interim Report, 1972. 1973, 1974.

(54) M. Liebrucks, "Econometric models for the energy sector of the Federal Republic of Germany," ECE Symposium on Mathematical Models of Sectors of Energy Economy, Alma-Ata, 1973.

(55) F. Rabar, "Simulation of investment policy in the energy economy," Case Western Reserve University, Working Paper No. 16, 1970.

(56) M. Petcu, Pap, Kovacs and Liciu, "Mathematical model for the optimization of the development of the basic energy supply of a country with a polyenergetic profile," 8th World Energy Conference, Bucharest, June 28-July 2, 1971.

(57) Model Group, U.K. Department of Energy (F.W. Hutber), "U.K. national energy model," London, 1972.

(58) M.L. Baughman, "Dynamic energy system modelling - interfuel competition," M.I.T. Energy Analysis and Planning Group, Report No. 72-1, September 1972.

(59) E.G. Cazalet, "SRI modeling capability," Stanford Research Institute, May 1974.

(60) E.W. Erickson, R.M. Spann and R. Ciliano, "Substitution and usage in energy demand: an economic estimation of long run and short run effects," in Energy Modeling, Milton F. Searl, ed., Resources for the Future, Washington, D.C., 1973.

(61) K. Hoffman, "A unified planning framework for energy system planning," Ph.D. thesis, Polytechnic Institute of Brooklyn, 1972.

(62) W. Nordhaus, "The allocation of energy resources," prepared for the Brookings Panel, November 1973.

(63) J. Richter and W. Teufelsbauer, "Österreichs Wirtschaft bis 1980, eine nach 31 Wirtschaftszweigen gegliederte Prognose mit Hilfe des I-O-Modells Austria II," Bundeskammer der gewerblichen Wirtschaft, Research Report No. 10, Vienna, 1973.

(64) D. Blain, "FINER - energy financing model," Ministère de l'Economie et des Finances, Paris, 1972.

(65) E.W. Henry and S. Scott, "Estimated price increases due to higher costs of petroleum and other imports," Economic and Social Research Institute, Dublin, 1973.

(66) K. Oshima, "A model for assessing energy utilization in the future," Industrial Research Institute, Tokyo, 1974.

(67) Institute of Energy Economics (M. Sakisaka), "A model for optimizing the allocation of energy to each industrial sector," Tokyo, 1973.

(68) Institute of Energy Economics (M. Sakisaka), "A model for assessing long term energy demand in Japanese economy," Tokyo, 1973.

(69) B.O. Karlsson, "Swedish economy from 1970 to 1977," Swedish Ministry of Finance, Stockholm, Reports SOU 1971-70, 1971 and SOU 1973-21, 1973 (in Swedish).

(70) F.G. Adams and P. Miovic, "On relative fuel efficiency and the output elasticity of energy consumption in Western Europe," Journal of Industrial Economics, Vol. 16, No. 1, November 1968.

(71) L.G. Brookes, "Energy and economic growth," Industrial Marketing Management, Vol. 1, No. 1, September 1971.

(72) L.G. Brookes, "More on the output elasticity of energy consumption," Journal of Industrial Economics, Vol. 21, No. 1, November 1972.

(73) L.G. Brookes, "Economic prosperity and nuclear power," Annals of Nuclear Science and Engineering, Vol. 1, 1972.

(74) R.A. Herendeen, "The energy cost of goods and services," Oak Ridge National Laboratory Report ORNL-NSF-EP-58, 1973.

(75) J.E. Just, "Impacts of new energy technology using generalized input-output analysis," M.I.T. Energy Analysis and Planning Group, Report No. 73-1, 1973.

(76) R.J. Rahn, "A dynamic model of energy and economic growth," Report prepared for the NSF, Dartmouth College, November 1973.

(77) P.K. Verleger, Jr., "An econometric analysis of the relationship between macroeconomic activity and U.S. energy consumption," in Energy Modeling, Milton F. Searl, ed., Resources for the Future, Washington, D.C., 1973.

(78) A. Voss, "Ansätze zur Gesamtanalyse des Systems Mensch-Energie-Umwelt," Kernforschungsanlage Jülich, Report Jul-982-RG, 1973.

(79) International Study Group on the LINK System (L.R. Klein), International Linkage of National Economic Models, R.J. Ball, ed., Amsterdam, 1973.

(80) M. Mesarovic and E. Pestel, Multilevel computer model of world development system, Proceedings of the Symposium, International Institute for Applied Systems Analysis, Laxenburg, Austria, April 29-May 3, 1974, Volumes I-VI and Summary.

(81) R. de Baw and F. Van Scheepen, "Problèmes posés par la conception et l'utilisation d'un modèle intégré concernant l'approvisionnement en énergie de la Communaute Européene," ECE Symposium on Mathematical Models of Sectors of the Energy Economy, Alma-Ata, 1973.

ANNEX II: PERSONS AND INSTITUTIONS CONTACTED

AUSTRIA

Bundesministerium für Handel
Gewerbe und Industrie
Stubenring 1
1011 Vienna

Prof. Dr. Hans Grümm
Österreichische Studiengesellschaft
für Atomenergie Ges.m.b.H
Lenaugasse 10
1082 Vienna

Österreichsches Institut für
Wirtschaftsforschung
Arsenal
Postfach 91
1103 Vienna

Dr. Josef Richter
Dr. Werner Teufelsbauer
Bundeskammer des gewerblichen
Wirtschaft
Biberstrasse 10
1010 Vienna

Dr. Tintner
Institut für Ökonometrie
Technische Hochschule Wien
Karlsplatz 13
1030 Vienna

BELGIUM

Mr. E. Debeys
Conseiller Principal
Sociétés Réunies d'Energie du
Bassin de l'Escaut (EBES), S.A.
Mechelsesteenweg 271
2000 Antwerp

Mr. P. Markey
Administration de l'Energie
Ministère des Affaires Economiques
49-51, Avenue de Trèves
1040 Brussels

Mr. M. de Falleur
Bureau de Plan
47-49, Av. des Arts
1040 Brussels

Prof. J. Waelbroeck
Département d'Economie Appliquée
(DULBEA)
Université Libre de Bruxelles
50, Av. F.D. Roosevelt 50
1050 Brussels

Mr. R. Groszmann
Directeur
Union des Exploitations
Electriques en Belgique
4, Galerie Ravenstain
1000 Brussels

Professeur H. Glesjer
Université Libre de Bruxelles
Terhuspsesteenweg 166
1170 Brussels

Service du Premier Ministre
Programmation de la Politique
Scientifique
8, rue de la Science
1040 Brussels

CORE
Université de Louvain
Louvain

Mr. M. Jaumotte
Faculté des Sciences Economiques
et Sociales
8, Rampart de la Vierge
5000 Namur

BULGARIA

Comité d'Etat de Planification
Institut Scientifique de
Planification Economique et
de Recherche
7 Noemvri I
Sofia

Institut Economique
Académie des Sciences de Bulgarie
ul. Axakov N. 3
Sofia

Institut Scientifique
Institut du Commerce Extérieur
Sofia

Mr. Kamenov
Energoproekt
bul. Anton Ivanov N. 56
Sofia

Mr. Luben Petkov
Energoproekt
bul. Anton Ivanov N. 56
Sofia

Mr. I.V. Peitchev
Collaborateur Scientifique
Centre Scientifique de Planification des Modèles Mathématiques
et des Prévisions du Développement
Social et Economique
58, rue Alabine
Sofia

CANADA

Mr. J.T. Bradley
Ministry of State for Science
and Technology
Ottawa, Ontario

Dr. Peter Meyboom
Director General
Science Procurement
Department of Supply and Services
Ottawa, K1A 0S5

Mr. Ross C. Richards
National Energy Board
Ottawa, Ontario K1A 0E5

Mr. J.M. Treddenick
Chief
Econometrics Division
National Energy Board
Ottawa 4, Ontario

Prof. Leonard Waverman
Depart. of Political Economy
University of Toronto
Toronto, Ontario

CZECHOSLOVAKIA

Mr. Bohuslav Cabicar
Head of Department
Energy Economy Section
Energy Research Institute
Nahrou de 19
Prague 10

Mr. Jiri Bouska
Econometric Laboratory
Czechoslovak Academy of Sciences
Politickych veznu 7
Prague 1

Mr. V. Bruha
Head of Department
Institute of Fuel and Power
Federal Ministry for Technical
Development
Sleska 9
Prague 2

Mr. Alexander Dano
Consulting Engineer
Ministerstvo vystavby a techniky SSR
ul Ceskoslovenskej armady 36
800 00 Bratislava

Mr. V. Fromek
Engineer-Economist
Department of Fuel and Energy
State Planning Commission
Nabr. kpt. Jarose 1000
Prague 7

Mr. Vlastimil Gejdos
Federal Ministry of Planning
Nabrezi Kpt. Jarose 1000
Prague 7

Mr. Bohumil Hanzel
Assistant Director
Ministerstvo vystavby a technicky SSR
ul. Csl. armady c. 36
800 000 Bratislava

Mr. Josef Klima
Engineer-Specialist
Fuel-Energetic Balance Section
State Planning Commission
Mabr. kpt. Jarose 1000
Prague 7

Mr. V. Kraus
Engineer-Specialist
Research Institute of Mining
Economics and Energy
Vladislavova 4
113 72 Prague 1

Mr. M. Marval
Head of Energy Development Depart.
Federal Ministry of Fuel and Energy
Stepanska 28
Prague 1

Mr. Stefan Mizera
Institute for Regional Planning
Kycerskeho
Bratislava

Mr. Miroslav Soucek
Research Institute of Economic Planning
U Sovovych Mlynu 9
Prague 1 - Kampa

Mr. D. Stratil
Computing Research Center
Dubravska cesto
Bratislava

Mr. Jaroslav Podzimek
Research Institute of Statistics
and Accounting
Sokolovska
Prague

Mr. D. Vaverka
Vice-Director
Institute of Fuel and Power
Federal Ministry for Technical
Development
Slezska 9
Prague 2

Mr. V. Wilda
Scientific Worker
Energy Development Department
Energy Research Institute
Karlova 2
Prague 1

Research Institute of Power
Partyzanska 7/a
170 84 Prague 7

Research Institute of Fuels and
Power Economy
Vladislavova ul. 4
110 00 Prague 1

CYPRUS

The Planning Bureau
Nicosia

GERMAN DEMOCRATIC REPUBLIC

Mr. P. Hedrich
Abteilungsleiter
Institut für Energetik
Torgauerstr. 114
7024 Leipzig

Mr. K. Lindner
Wissenschaftlicher Mitarbeiter
Institut für Energetik
Torgauerstr. 114
7024 Leipzig

Mrs. U. Reymann
Wissenschaftliche Mitarbeiterin
Institut für Energetik
Torgauerstr. 114
7024 Leipzig

Prof. Dr. J. Rudolph
Hochschule für Ökonomie Berlin
Dunckerstrasse 8
1157 Berlin-Karlshorst

Staatplannungs-Komission
Leipzigerstr. 5/7
108 Berlin

DENMARK

Mr. Sven Bjørnholm
The Niel Bohr Institute
University of Copenhagen
Copenhagen

Mr. J.E. Yndgaard
Institute of Economics
University of Aørhus
NDR. Ringgade
Universitetsparken
8000 Aørhus

Economic Council
Norre Voldgade 68
Copenhagen K

The Economic Secretariat
Ministry of Economic Affairs
Slotholmagade 10
Copenhagen K

Danmarks Statistik
Frederiksholms Kanal 27
1220 Copenhagen K

FEDERAL REPUBLIC OF GERMANY

Mr. R. Bieselt
Institut für Elektrische Anlagen und
Energiewirtshaft der
Technische Hochschule Aachen
Templergraben 55
5100 Aachen

Prof. Dr. Ing. W. Dreger
Zentrum Berlin für Zukunftsforschung e.V.
Giesebrechtstrasse 15
1 Berlin 12

Mr. M. Liebrucks
Division of Mining and Energy
Economics
Deutsches Institut für Wirtschafts-
forschung
Königin-Luisestr. 5
1 Berlin 33

Dr. Helmut Maier
Technische Universität Berlin
Institüt für Stadt- und
Regionalplanung
Strasse des 17 Juni 135
1000 Berlin 12

Mr. W. Meier
Mr. A. Voss
Kernforschungsanlage Jülich
517 Jülich 1

Prof. E. Pestel
Technische Hochschule
Lehrstuhl A für Mechanik
Hannover

Ministerialrat
Heinrich Quante
Energy Analysis and Projections
Energy Division
Bundesministerium für Wirtschaft
Villemomblerstr. 76
53 Bonn

Prof. R. Thoss
Institut für Siedlungs- und Wohnungwesen der Universität Münster
Am Stadtgraben 9
44 Münster

FINLAND

K.O. Huuskonen
Head of Statistical Office
Neste Oy, Kaivokatu 10A
00100 Helsinki 10

M.A. Jaakonaho
Senior Economist
Study Group for Economic Research on Energy
Bank of Finland
Hämeenkatu 2 A2
20500 Turku 50

I.H. Lavonius
Chief Inspector
Industrial Department
Energy Policy Branch
Ministry of Trade and Industry
Aleksanterinkatu 10
00170 Helsinki 17

Mr. Erkki Laate
Economic Planning Centre
Erottaja 15 A
Helsinki 13

Mr. Erik Törnqvist
Ministry of Finance
Economic Department
Fabianinkatu, 8
00130 Helsinki 13

Economic Research Institute for Finnish Industry
Kalevankatu 3B
Helsinki 10

Bank Finland
Institute for Economic Research
Box 10 160
Helsinki 10

FRANCE

Monsieur D. Blain
Chargé de Mission
Ministère de l'Economie et des Finances
Direction de la Prévision
Sous-Direction "C"
9, rue Croix des Petits Champs
75001 Paris

Monsieur E. Bauer
Institut National des Sciences et Techniques Nucléaires
Adjoint au Directeur
B.P. No 1
91 Gif-sur-Yvette

Monsieur Destival
Rapporteur Général de la Commission de l'Energie
18, rue de Martignac
75007 Paris

Monsieur Y. Girard
Chargé de Mission
Délégation Générale à l'Energie
35, rue Saint-Dominique
75007 Paris

Monsieur Hebert
Service de la Statistique
83, Bd. de Montparnasse
75006 Paris

Monsieur R. Janin
Chef de Service des Etudes Economiques Générales
Electricité de France
2, rue Louis Murat
75008 Paris

Monsieur D. Levi
Service des Etudes Economiques
Générales
Electricité de France
2, rue Louis Murat
75008 Paris

Monsieur J.M. Martin
Université de Grenoble - I.R.E.P.
Institut Economique et Juridique
de l'Energie
Domaine Universitaire de
St-Martin d'Hères
B.P. 47 - Centre de tri 38040
Grenoble Cedex

Monsieur J. Masseron
Directeur
Centre d'Etudes Supérieures
d'Economie Pétrolière
I.F.P.
B.P. 18
92 Rueil Malmaison

Monsieur Pierre
Chef du Département des Programmes
Commissariat à l'Energie Atomique
29-33, rue de la Fédération
75015 Paris

Monsieur Ramain
Université de Grenoble - I.R.E.P.
Institut Economique et Juridique
de l'Energie
Domaine Universitaire de
St-Martin d'Hères
B.P. 47 - Centre de tri 38040
Grenoble Cedex

Monsieur L. Thiriet
Chargé des Etudes Economiques
Générales
Département des Programmes
Commissariat à l'Energie Atomique
29-33, rue de la Fédération
75015 Paris

HUNGARY

Mr. G. Daniel
Engineer
Eroterv
Sze chenyi rkp. 3
1054 Budapest

Mr. P. Erdosi
Head of Dept.
National Board for Power and Fuel
Economy
Marko utca 16
1955 Budapest

Mr. G. Fekecs
Department Chief
Computer Centre of National Planning
Office
Amgol u. 27
1149 Budapest

Mr. G. Foldvary
Technical Economic Adviser
National Board for Power and Fuel
Economy
Marko utca 16
1055 Budapest

Mr. T. Füredi
Chief Engineer
National Board for Power and Fuel
Economy
Marko utca 16
1055 Budapest

Mr. M.L. Halabuk
Econometric Laboratory
Central Statistical Office
Keleti Karoly u. 5-7
Budapest II

Mr. S. Komariomi
Chief of Department
National Inspectorate of Energy
and Safety
Attila u. 99
1253 Budapest Pf. 19 I.

Mr. K. Patyi
Senior Research Worker
OT. Tervazdasagi Intezet
Münnich F. u. 13
1051 Budapest

Mr. J. Peto
Chief of Department
Eroterv
Szechenyi rkp. 3
1054 Budapest

Dr. F. Rabar
Director
System Engineering Institute
11 Tarogato ut. 110
Budapest

Mr. M. Tardes
Head of Department
Institute for Economic and Market Research
Dorottya u. 6
Budapest V

Mr. G. Vajda
Director
Institute for Electrical Power Research
Veiki
POB 233
1368 Budapest

Mr. T. Zettner
Managing Director
Hungarian Electricity Board
Iskola 13
1011 Budapest

Institute of Economics
Hungarian Academy of Sciences
Münich Ferenc utca 7
Budapest

Institute of Finance
Jozsef Nader ter 2-4
Budapest V

GREECE

Mr. C. Delis
Chef du Service de Planification Economique
Entreprise Publique d'Electricité de Grèce
4, rue Aloupekis
Athens

Centre of Planning and Economic Research
Hippokratous 22
Athens 144

The Director
Institute of Economic Research
Hippokratous 22
Athens 144

Director of Planning Services
Ministry of Coordination
3 Amerikis Street
Athens

ICELAND

The Economic Institute
Reykjavik

IRELAND

Department of Finance
Economic Development Branch
72-76 St. Stephen's Green
Dublin 2

Mr. E.W. Henry
Quarterly Economic
Economic and Social Research Institute
4, Burlington Road
Dublin

ITALY

Dott. Benevolo & Dott. Sfigiotti
ENI
EUR
00100 Rome

Prof. Leardini
Ufficio Studi e Ricerche
ENEL
via G.B. Martini, 7
00100 Rome

Dott. Sillitti
Istituto Studi Programmazione
Economica
00100 Rome

Prof. Valtorta
Ufficio Programmazione
ENEL
via G.B. Martini, 7
00100 Rome

JAPAN

Prof. K. Oshima
c/o The Institute of Industrial
Research
Nisshin Bldg.
7-1-2 Shinkawa
Chuo-ku
Tokyo

Mr. Mituo Takei
Manager
Research Division
The Institute of Energy Economics
10 Mori Bldg
28, Shiba-Nishikubo Sakuragawa-cho
Minato-ku
Tokyo

LUXEMBURG

Service d'Expansion Economique
Ministère des Affaires Economiques
Luxemburg

NETHERLANDS

Mr. W.L.M. Adriaansen
Ministry of Economic Affairs
Bezuidenhout 30
The Hague 2000

Mr. Marcus Josephus Stoffes
Centraal Planbureau
von Stolweg 14
's-Gravenhage

Centraal Bureau voor de Statistiek
Bureau Statistische Analyse
Oostduinlaan 2
's-Gravenhage

Centre for Development Planning
Burgneester Oudlaan 50
3016 Rotterdam

Economic Institute
Erasmus University
Burg. Oudlaan 50
3016 Rotterdam

Economische Instituut der Katholieke
Hogeschool
Hogeschoollaan 225
Tilburg

Economisch Instituut der Universiteit
Oude Boteringestraat 23
Groningen

Economisch Instituut der Vrije
Universiteit
Boelelaan 1115
P.B. 7161
Amsterdam-Z II

Instituut voor Actuariaat an
Econometrie der Universiteit
Nieuwe Achtergracht 170
Amsterdam-Z I

Landbouw Economisch Instituut
Conradkade 175
's-Gravenhage

Nedelands Economisch Instituut
Division of Balanced International
Growth
Burg. Oudlaan 50
Rotterdam

Studie-afdeling van bet Ministerie
van Verkeer en Waterstaat
Binnenhof 20
´s-Gravenhage

Studiedienst van der Nederlansche
Bank N.V.
Post Box 98
Amsterdam

MALTA

Mr. S. Busuttil
Department of Applied Economics
The Royal University of Malta
Msida

Central Office of Statistics
Windmill Street
Valletta

Economic Planning Division
Office of the Prime Minister
Auberge d´Aragon
Valletta

NORWAY

Prof. L. Johansen
University of Oslo
Institute of Economics
Box 1071
Blindern
Oslo 3

Central Bureau of Statistics
Research Division
Oslo

Ministry of Finance
Planleggingsavdelingen
Akersgt 42
Oslo

Ministry of Finance
Okonomiavdelingen
Akersgt 42
Oslo

Norges Handelshogskole
The Norwegian School of Economics and
Business Administration
Helleveien 30
5000 Bergen

Norges Tekniske Hogskole
Institute for Sosialokonomi
7034 Trondheim

Transportokonomisk Institutt
Stasjonsvn 4
Oslo 3

POLAND

Mr. S. Czosnowski
Chief Consultant on Energetics
Ministry of Science
Higher Education and Technology
ul Miodowa 6/8
Warsaw

Mr. D. Deja
Chief of Section
Department of Fuel and Energy
Planning Commission by Council of
Ministers
Pl. 3 Krzyzy 3/5
Warsaw

Mr. Z. Falecki
Director
Scientific Centre for Energy Problems
Central Mining Institute (OEK)
Pl. Gwarkow 1
Katowice

Mr. W. Frankowski
Head, Dept. of Nuclear Power
Institute of Nuclear Research
Swierk k. Otwocka
Warsaw

Mr. M. Hajdasinski
Lecturer
Institute for Projecting and Building
of Mines
Academy of Mining and Metallurgy
Mickiewicza 30
Krakow

Mr. S. Hatt
Planning Commission
Division for Economic Analysis
Plac 3 Krzyzy
Warsaw

Mr. J. Holubiec
Head of Department
Polish Academy of Sciences
Institute of Applied Cybernetics
Warsaw KRN 55

Mr. M. Jawien
Akademia Gorniczo Hutnicza
Krakow

Mr. J. Mikulski
First Deputy Director
Scientific Center for Energy Problems
Central Mining Institute (OEK)
Pl. Gwarkow 1
40-951 Katowice

Mr. R. Nowakowski
Head of Laboratory
Instytut Energetyki
Mysia 2
00-496 Warsaw

Economic Research Centre
Central Statistical Office
Al. Niepodleglosci 208
Warsaw 58

Foreign Trade Research Centre
Frascati 2
Warsaw

Institute of Planning
Plac Trzech Krzyzy 5
Warsaw

Krejowe Biuro Informatyki
ul. Jasna 14/16
Warsaw 1

Nuclear Research Centre
Swierk

Research Department
State Statistical Office
ul. Wawelska 1/3
Warsaw

PORTUGAL

Mr. F. Algada
Technicien Economiste
Direccao-Geral dos Combustiveis
Rua da Beneficencia 241
Lisbon

Mr. Rui Sergie
Technicien Engenieur
Gabinete de Planeamento Secretaria
de Estado da Industria
Rua das Pracas 13 B 1
Lisbon

Comisao Tecnica de Cooperacao
Economica Externa
Avenida da Republica 32-1
Lisbon

Fundacao Calouste Gulbenkian
Centro de Estudos de Economia Agraria
Oeiras

Instituto Nacional de Investigacao
Industrial
Rua das Pracas, 51 R/C Dto
Lisbon

Junta Naciononal de Investigacao
Cientifica e Tecnologia
Presidencia de Conselho
Lisbon

Secretariado Tecnica da Presidencia
do Conselho
Rua Diogo Couto 1
Lisbon

RUMANIA

Mr. M.P. Constaninescu
Directeur
Centre pour Perfectionnement des
Cadres Dirigeants, Section de
Recherche Operationnelle
Soseaua Odai No 20
Otopeni Bucharest

Mr. M.V. Ionescu
Secrétaire Scientifique
Centre de Calcul Economique et
Cybernetique Economique
Academie des Sciences Economiques
Str. Mihail Eminescu 5-7
Bucharest

Mr. M.R. Iordanescu
Secrétaire Scientifique
Institut de Mathématique de
l'Academie des Sciences
Calea Grivitei 21
Bucharest 12

Mr. Jankovitch
Le Comité d'Etat du Plan
Calea Victoriei 152
Bucharest

Mr. N.M. Mares
Directeur
Centre de Calcul Mécanisé et
Electronique du Ministère des
Transports
Str. Garii de Nord No. 1
Bucharest

Mr. M. Petcu
Institut de
Recherches d'Energétique
Industrielle et de Projets
d'Outillages Energétique
Bucharest

Mr. M.I. Sacuiu
Secrétaire Scientifique
Centre de Statistique Mathématique
de l'Académie des Sciences
Calea Grivitei 21
Bucharest 12

Mr. Romert Victor
Directeur
Direction du Système Energétique de
la Centrale Industrielle pour la
Production de l'Energie Electrique
et Termique
Bulevardul Hristo Botev 14-16
Bucharest

Institut d'Etudes et de Recherches
pour la Planification
Calea Vicotriei 152
Bucharest

SWITZERLAND

Prof. Blanc
Institut de Mathématiques Appliquées
de l'Ecole Polytechnique Fédérale
33, Avenue de Cours
1000 Lausanne

Prof. Dr. R. Bombach
Institut für angewandte Wirtschafts-
forschung
4000 Bale

Mr. M.Y. Fishman
Ingenieur en Chef
Société Génerale pour l'Industrie
9, Chemin des Délices
1000 Lausanne 13

Prof. B. Fritsch
Institut für Wirtschaftsforschung
an der ETH
Universitätsstr. 14
8006 Zürich

Dr. V. Sohenk
Schweizer Botschaft
Prinz-Eugenstr. 7
1030 Vienna

Prof. L. Solari
Centre d'Econométrie
Faculté des Sciences Economiques
et Sociales
6, rue de Saussure
Geneva

Le Délégué aux questions conjonturelles
Effingerstrasse 55
3003 Berne

Forschungsgemeinschaft für National-
ökonomie an der Hochschule St. Gallen
für Wirtschafts- und Sozial-
wissenschaften
Dufourstr. 50
9000 St. Gallen

Forschungstelle für Operations Research
und Ökonomie an der Hochschule
St. Gallen fur Wirtschafts- und
Sozialwissenschaften
Dufourstr. 40a
9000 St. Gallen

Institut de Recherches Economiques
Ecole Polytechnique Fédérale
Scheuchzerstr. 68
8006 Zürich

Institut des Sciences Economiques
et Sociales
Université de Fribourg
1700 Fribourg

Institut für Operations Research
und elektronische Datenverarbeitung
der Universität Zürich
Sumatrastr. 30
8006 Zürich

Institut pour l'Automation et la
Recherche Opérationnelle
Université de Fribourg
1, route du Jura
1700 Fribourg

SWEDEN

Mr. K.H. Aberg
The National Institute of Economic
Research
Nybrokaien 13
Stockholm

Mr. E.S. Ben Salem
Chief of the Swedish Government
Committee for Energy Forecasting
Munkbron 11, ltr, EPU
11128 Stockholm

Mr. Göran Bergendahl
University of Gothenburg
Vasaparken
41125 Gothenburg

Mr. B.O. Karlsson
The Swedish Ministry of Finance
Secretariat for Economic Planning
Riddarhustorget 7-9, Fack
103 10 Stockholm 2

Mr. R. Stälebrant
Chief Engineer
Stockholms Elverk
Fack 104 32
Stockholm 19

The Industrial Institute for
Economic and Social Research
Box 5037
102 41 Stockholm 5

SPAIN

Mr. Espi
Comisaria del Plan del Desarrollo
Eonomico y Social
Castellana 3
Madrid

Mr. R. Vazquez Candame
Secrétaire
Institut du Développement Economique
Antigua Universidad de Alcala de
Henares
Madrid

THAILAND

Dr. Marzouk
Deputy Director
ECAFE
Research and Planning Division
Sala Santitham
Bangkok

TURKEY

Mr. Mücteba Buharalilar
Consultant
Elektrik Isleri Etüt Idaresi
Ankara

Mr. M.O. Tarkan
Turkish Electricity Authority
TEK, Planlama ve Koordinasyon D.
Necatibey Cad. 36
Ankara

State Planning Organization
Bakanliklar
Ankara

U.K.

Mr. F.P. Jenkin
Central Electricity Generating
Board
Sudbury House
15 Newgate Street
London EC1

Mr. L.G. Brookes
U.K. Atomic Energy Authority
11, Charles II Street
London SW1 4PQ

Mr. D. Burnet
Mathematical Analyst
Northern Ireland Joint Electricity Authority
P.O. Box 46
12, Manse Road
Castlereagh
Belfast BT6 9RT

Prof. R.J. Deam
Energy Group
Queen Mary College
Mile End Road
London E1 4NS

Dr. R. Eden
Cavendish Laboratory
Department of Physics
University of Cambridge
Cambridge CB2 3RQ

Mr. F.W. Hutber
Economic and Statistics Division
Department of Trade and Industry
Thames House South, Millbank
London SW 1P 4QJ

Mr. C.E. Iliffe
Reactor Group
U.K. Atomic Energy Authority
Risley, Warrington, Lancs.

Dr. Jones
Programmes Analysis Unit
Chilton, Didcot, Berks. OX 11ORF

Mr. Peter Roberts
System Analysis Research Unit
Department of the Environment
Marsham Street
London SW1P 3EB

Depart. of Pure and Applied Chemistry
University of Strathclyde
295 Cathedral Street
Glasgow G1 1XL

U.S.A.

Mr. Robert Ayres
International Research and Technology Corp.
1225 Connecticut Ave., W.
Washington, D.C. 20036

Mr. F.G. Adams
Mr. P. Miovic
University of Pennsylvania
Philadelphia, Penn. 19104

Dr. M.L. Baughman
Energy Analysis and Planning Group
Massachusetts Institute of Technology
Cambridge, Mass. 02139

Mr. E.S. Cazalet
Senior Decision Analyst
Stanford Research Institute
Menlo Park, Calif. 94025

Prof. Thomas J. Connolly
Department of Mechanical Engineering
Stanford University
Stanford, Calif. 94305

Mr. E.A. Copp
Economist
American Petroleum Institute
1801 K Street, N.W.
Washington, D.C. 20550

Mr. P.P. Craig
Office of Energy Policy
National Science Foundation
1800 G Street, N.W.
Washington, D.C. 20550

Mr. E. Erickson
Associate Prof. of Economics
North Carolina State University
Box 5368
Raleigh, North Carolina 27607

Dr. Robert A. Herendeen
Oak Ridge National Laboratory
Oak Ridge, Tenn. 37830

Dr. K. Hoffman
Brookhaven National Laboratory
Dept. of Applied Science
Building 902
Upton, L.I., New York 11973

Prof. Hendrik Houthakker
Department of Economics
Harvard University
Cambridge, Mass. 02138

Prof. Dale Jorgenson
Department of Economics
Harvard University
Cambridge, Mass. 02138

Prof. Gordon Kaufman
Sloan School of Management
Massachusetts Institute of Technology
Cambridge, Mass. 02139

Prof. L.R. Klein
University of Pennsylvania
Philadelphia, Penn. 19104

Prof. P.W. MacAvoy
Sloan School of Management
Massachusetts Institute of Technology
Cambridge, Mass. 02139

Prof. A.S. Manne
Harvard University
John Fitzgerald Kennedy School
of Government
Littauer Center
Cambridge, Mass. 02138

Prof. M. Mesarovic
Case Western Reserve University
Cleveland, Ohio

Mr. William E. Mooz
Rand Corporation
1700 Main Street
Santa Monica, Calif. 90406

Prof. William Nordhaus
Department of Economics
Yale University
New Haven, Conn. 06520

Dr. R.J. Rahn
Research Program on Technology and
Public Policy
Thayer School of Engineering
Dartmouth College
Hanover, N.H. 03755

Dr. Sam H. Schurr
Electric Power Research Institute
3412 Hillview Ave.
P.O. Box 10412
Palo Alto, Calif. 94304

Mr. R.M. Spann
Professor of Economics
Virginia Polytechnic Institute
Blacksburg
Virginia

Mr. P.K. Verleger, Jr.
Senior Economist
Data Resources Inc.
29 Hartwell Ave.
Lexington, Mass. 02173

Prof. David White
Massachusetts Institute of Technology
Energy Laboratory
Bldg. 39-592
Cambridge, Mass. 02139

Data Resources Inc.
Energy Research
29 Hartwell Ave.
Lexington, Mass. 02173

Decision Sciences Corporation
Benjamin Fox Pavilion
Jenkintown, Pa. 19046

The Energy Policy Project
1755 Massachusetts Avenue, N.W.
Washington, D.C. 20036

U. S. S. R.

Mr. S.A. Avramenko
The Computing Centre of the State
Planning Commission of the
Ukrainian SSR
Kiev, Ukrainian SSR

Mrs. I.N. Bessonova
G.M. Krzhizhanovsky State Research
Institute of Energetics
Academy of Sciences of the USSR
Leniuskij pr. 14
Moscow

Prof. V. Gluskov
Institute for Cybernetic AS. Ukz SSR
Kiev, Ukrainian SSR

Prof. S. Jampolsky
Institute of Economics of the
Academy of Sciences Ukz SSR
Kiev, Ukrainian SSR

Dr. V. Medvedev
Scientific Research Institute of
Economic and Economic-Mathematical
Planning Methods
Gosplan, BSSR
1 Slavinskogo
Minsk 23

Dr. A.I. Mekibel
Central Economic Mathematical
Institute
Dept. of Economics
2nd Yaroslavskaya ul 3
Moscow

YUGOSLAVIA

Mr. M. Alaksic
Director
Foreign Trade Research Institute
Mose Pijade No 8
Belgrade

Mr. D. Bjelogrilic
Director
Ekonomiski Institute Sr. Srbije
P.O. Box 402
Belgrade

Mr. Branko Horvat
Director
Institute of Economic Studies
Smaj Jovina 12
Belgrade 11000

Mr. V. Lackovic
Director
Republican Planning Institute of S.R.
Croatia
Strosmayera trg. 9
Zagreb

Dr. R. Lang
Director
Economic Institute
J.F. Kennedy-a 7
Zagreb

Mr. Markovic
Institut Fédéral de Statistique
Knesa Milosa 20
Belgrade

Mr. V. Medenica
Federal Institute for Economic
Planning
Knesa Milosa 20
Belgrade

Mr. C. Mijic
Conseiller
Eleh (Poslovno ndrnzerje electro-
privredmili organizaciaja SR
Irvatsre)
P.O. Box 616
41001 Zagreb

Mr. S. Obradovic
University Professor
Svetog Nanma 14
Belgrade

Dr. G. Pockar
Institut za Ekonmska Raziskovanja
Gorupova ul. 7
Ljubljana

Mr. Hrvoje Pozar
University Professor
Elektrotehnicki Fakultat Zagreb
TRG Maršala Tita 14
P.O. Box 815
41001 Zagreb

Prof. V. Rupnik
Research Centre of the Faculty of
Economics of the University
TRG Revducije 11
Ljubljana

Mr. Simonovic
Director in Zeps
Internacionale brigade No. 1
Belgrade

Mr. Todorovic
Research Addociate
Institute for Industrial Economics
Marsala Tita 16/11
Belgrade

Mr. B. Udovicic
Ingenieur Diplome
Institut de l´Electricité
41000 Zagreb

Institute for Industrial Economics
Marsale Tiat 16
Belgrade

Institute ofr Planning and Management
Systems
Faculty of Political Sciences
Jove Ilica 165
Belgrade

INTERNATIONAL ORGANIZATIONS

Monsieur Laading
O.E.C.D.
Chef de la Division de l´Energie
Direction de l´Industrie et de l´Energie
2, rue André Pascal
75016 Paris
FRANCE

Mr. R. Krymm
Head of Economic Study Section
Division of Nuclear Power and Reactors
I.A.E.A.
Kärntner Ring 11
1010 Vienna
AUSTRIA

Mr. Brendow
Mr. C. Lopez-Polo
United Nations
Economic Commission for Europe
Palais des Nations
1211 Geneva 10
SWITZERLAND

Mr. Van Scheepen
Commission of European Communities
200, rue de la Loi
1040 Brussels
BELGIUM