A REVIEW OF ENERGY MODELS
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J.-M. Beaujean and J.-P. Charpentier, Editors

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PREFACE

This review is the fourth in the IIASA series of publications reviewing energy models. This work is related to the project, Comparison of Energy Options: A Methodological Study, carried out jointly by the United Nations Environment Programme and IIASA. The series has been set up to aid the student of the energy problem in his literature search for a tool applicable to his set of problems and to avoid duplication of efforts.

The present review contains only 14 models. There is a tendency toward modification and actualization of existing models, and research institutions are, understandably, reluctant to provide them in incomplete form. A list of the institutions and individuals contacted is appended to this report.

We hope that this review will stimulate contacts and collaboration between specialists. For a continuation of this series readers are invited to provide the editors with abstracts of their energy models.

Jean-Pierre Charpentier, *A Review of Energy Models: No. 1–May 1974*, Revised September 1976, RR-74-10, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

Jean-Pierre Charpentier, *A Review of Energy Models: No. 2–July 1975*, RR-75-35, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

Jean-Michel Beaujean and Jean-Pierre Charpentier, eds., *A Review of Energy Models: No. 3–December 1976*, Special Issue on Soviet Models, RR-76-18, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976.

SUMMARY

Fourteen new models are presented in this review; their classification is shown in the table below. Of type A there are four models; of types C, E, and F, three each; of type B, one model and none of class D.

The preceding three reviews of energy models have clearly shown that there are few energy models linking energy systems to the overall economy and even fewer models combining demand and supply consistently. In the present review there are three models of these types: the Swedish model developed by Carl Bergström et al.; Coal 1 by R. Naill; and the model of the refining industry in Belgium by Franz Jomaux.

Models' Classification

Areas of Application		National	International
Energy System (energy is the main problem)	One kind of fuel	A 4	B 1
	Several kinds of fuel	C 3	D 0
Linkage between energy and general economy		E 3	F 3

List of Models

Country	No.*	Title and Author	Class
Belgium	B401	Study of the Optimal Structure of the Belgium refining industry Franz Jomaux, Faculté Universitaire Catholique de Mons	A
Canada	CDN401	Optimal Sales Policy for Canadian Natural Gas Ross C. Richards, Energy Models Div., National Energy Board	B
Japan	J401	A Simulation Model for Study of the Dynamic Behavior of Crude Oil Production in Middle East Oil Exporting Countries Teruyasu Murakami, Nomura Research Institute	F
Mexico	M401	"Mexico"--National Energy Model J. Lartigue G., University of Mexico	E
Netherlands	N401	Mining Industry Model IRC-004 J.W. Brinck, IRC-Brinck International Resources Consultants B.V.	A
New Zealand	NZ401	A Planning Model of New Zealand's Energy Industry B.R. Smith, P.D. Lucas and B.A. Murtagh, Victoria University and Ministry of Energy Resources	C
Sweden	S401	An Energy Forecasting Model for Sweden Lars Bergman, Clas Bergström, and Anders Björklund, Economic Research Institute, Stockholm School of Economics	E
Turkey	T401	Energy System Planning Mini-Model I. Kavrak, Boǧazici University	C
UK	GB401	Demand for Energy Forecasting Model G. Kouris, University of Surrey	F
UK	GB402	Model for Estimating Price Increases Due to Higher Costs of Petroleum and Other Imports E.W. Henry and S. Scott, Quarterly Economic Commentary	E

*Numbers refer to abstracts of the models stored on the IIASA computer.

Country	No.	Title and Author	Class
USA	USA401	A Regional Linear Programming Approach to the United States Energy System P.J. Nagarvala, G.C. Ferrell and L.A. Olver, Bechtel Corp.	A
USA	USA402	COAL 1: A Model of the United States Energy System Roger Naill, Thayer School of Engineering, Dartmouth College	A
USA	USA403	The Energy Supply Planning Model M. Carasso and J.M. Gallagher, et al., Bechtel Corp.	C
EC	XX401	Evaluation of Power Station Installation Policies F. Conti, G. Graziani and C. Zanantoni, Commission of the European Communities	F

MODELS CLASS A

The Model	A regional linear programming approach to the United States energy system. (USA401) P.J. Nagarvala, G.C. Ferrell*, and L.A. Olver, Bechtel Corporation, San Francisco, California, 1974.
Subject and Goal	The model is concerned with optimal regional flows and the utilization of different energy forms, with an emphasis on coal and clean coal energy. The model permits interfuel substitutability, and includes a wide range of existing and developing technologies. It develops a methodology for the planning and analysis of complete energy systems from mining and extraction through energy conversion and transportation, environmental considerations, and energy demand.
System Description	The model deals with a regional US energy system that currently emphasizes the coal and coal-based energy sectors. The model constructs and analyzes optimal systems of energy utilization based on regional descriptions, energy supplies, transportation networks, regional characteristics and availabilities of energy conversion facilities, environmental control techniques, and energy demands. The model is data driven and capable of creating and analyzing a wide variety of energy system descriptions.
Area — Time	Single time period. Model runs may be made for each time period of interest. The model has been applied for the years 1980 and 1985.
Area — Space	Flexible. The US, or any chosen subregion included in the model boundary, may be disaggregated as desired. The model has been applied to the US for a five- and a sixteen-region breakdown.
Modeling Techniques	This is an optimization model that uses linear programming and extensions. The model creates and/or manages the LP matrices and submatrices, using input data and logical information tables. It calculates feasible and optimal primal/dual solutions, and generates a hierarchy of output reports. The technique has user interactive capability and flexible interface capacity.
Input Data — Operational	The user specifies regions, year, supply and demand categories, transportation options, energy conversion technologies, maximum interfuel substitution levels, technical and economic logical structures, and the optimization objective.
Physical	The following are required by region: coal reserves; mining capacity by coal price and coal category; availability and price of domestic and imported natural gas and crude; import and export of coal and electric power; demand by energy form--electric, raw coal, gas, crude, and refined products. When regional data are unavailable, algorithms are developed to disaggregate US level information as necessary.
Technical	The required data are the economics, physical capacities, and efficiencies of energy technologies, including coal transportation (rail, unit train, waterborne carrier, and slurry pipeline); oil and gas pipelines; electric transmission; fossil-fuel steam-electric power plants (coal, oil, and gas); hydroelectric, nuclear, and other electric power generating facilities; coal synthetic facilities (gasification, liquefaction, solid); fluidized bed combustion; advanced fossil fuel systems.
Resources and Environment	Energy resources including manpower, materials, and capital are not now, but may be, incorporated as accounting or constraining rows in the model structure. Water and capital resources have been investigated. Environmental residual emissions may be accounted for or constrained. SO_x emissions have been investigated and constrained.
Economic	The objective function, which may be other than economic, includes the average single-time period cost of fuel supplies, and the cost of maintaining or constructing energy conversion facilities. Facilities scheduled to be in existence and additional facilities required by the model are differentiated.
Output Data — Operational	A hierarchy of output reports showing input and output data for the optimal energy system for each year, region, and energy/economic sector.
Physical	The optimal configuration of energy technologies to meet demands from available supplies subject to resource and environmental criteria.
Resources and Environment	Energy-related resources (e.g., water, capital, etc.). Environmental emissions (e.g., SO_x).
Economic	Economic input data and marginal costs for all constrained activities (e.g., coal mining capacity, SO_x emissions, regulations.
Observations	The model may be used to determine regional implications of national energy scenarios. It contains a detailed coal resource and coal-energy technology data base. Energy supply and demand is disaggregated by region. Non-coal systems are managed exogenously at present. Interfuel substitutability is included, but no direct provisions are made for price/demand elasticities. (These may be analyzed iteratively.) Work is proceeding to expand the model to include endogenously all energy sectors, incorporating their resource and environmental implications. The model provides a methodology that may be used to assess the regional impact of various national energy scenarios and, by highlighting bottlenecks, may serve as a guide to R&D policymakers.

*Initial project leader; now associated with the University of California, Berkeley.

NETHERLANDS

The Model		Mining industry model IRC-ØØ4. (N4O1) J.W. Brinck, IRC-Brinck International Resources Consultants B.V., P.O. Box 471, Alkmaar 1700, Netherlands, 1975/1976.
Subject and Goal		Valuation of mineral prospects, deposits, districts, and provinces in particular; and estimation and comparison of the mineral potential (inferred resources) of countries, continents, and the world, in general.
System Description		The estimation of mineral resources is based on the assumption of a log-binomial frequency distribution of element concentrations in the geologic environment. This distribution creates a probability field for mineral deposits of different size-grade specifications, which determines the rarity of such deposits and thus their average exploration costs. Their size and grade determine the average required capital investment and exploitation costs as well as the optimum production capacity to be installed for a given minimum rate of return on invested capital. The assumption that the frequency distribution of the concentrations will logistically approach a theoretical or practical concentration barrier, as proposed by DE WIJS (1975), can be tested and evaluated.
Area	Time	All economic estimates are made on the basis of current technology and historical cost-price relations for the moment that a fully equipped deposit should enter into production.
	Space	Unspecified. Local and regional conditions are compared with global conditions (individual deposits and global resources).
Modeling Techniques		The probability field of global resources of a mineral commodity is calculated from mineral deposits in different price categories (reserves, marginal and submarginal resources). Individual prospects, the results of geochemical surveys or estimates of a national potential, are compared with their global equivalents.
Input Data		The data requirements are empirical estimates or measurements of demonstrated reserve and other mineral concentration parameters, and cost of exploration and production as a function of size-grade specifications for mineral deposits. The standard economic parameters have been checked against production statistics of over 500 major and minor mines in the Western world, producing a wide variety of mineral commodities. Optionally, these parameters can be varied to comply with special conditions for individual deposits or prospects.
Output Data		The data requirements are as follows: global or local probabilistic distribution of mineral concentrations of different size-grade specifications and related production costs with respect to a statistically determined target price; estimates of inferred reserves and resources for a given geological environment; favorability index for deposits, exploration targets, or territories as compared with their global equivalents.
Observations		The model is the basic unit of a software package, being developed by IRC, that will be used for the direction and interpretation of mineral exploration activities. The computer programs and descriptions can be made available on a lease basis in the Honeywell-Bull Time Sharing System; on special request, they can be adapted to other computer systems.

USA

The Model	COAL 1: A model of the United States energy system. (USA402) Roger Naill, Thayer School of Engineering, Dartmouth College, Hanover, New Hampshire.
Subject and Goal	COAL 1 is a dynamic model of the US energy supply and demand system. COAL 1 is a policy model designed to help reveal the soundest policy combinations for insuring smooth transition, with minimum dependence on foreign oil and gas, from finite domestic fuel sources (coal, nuclear, oil, and gas) to ultimate sources (fusion, and solar).
System Description	The model reproduces the structure and behavior of the US energy system, conceptualized as four gross interacting sectors: oil and gas, electricity, coal, and demand. The model contains an appropriate structure to represent domestic fuel resource depletion, interfuel competition and substitutability, environmental effects of nuclear and coal development, competition for available energy capital, changes in coal industry labor supply, government regulation of alternative development options, and the role of energy imports. The following strategies for energy self-sufficiency are examined: business as usual; accelerated nuclear development; expansion of the coal industry; more rapid technological advances such as the implementation of retrofitted stock scrubbers, and synthetics development; changes in environmental and worker-safety standards; capital-stimulation and capital-allocation biases; and reduced growth in energy demand.
Area — Time	1970-2010.
Area — Space	USA as a whole.
Modeling Techniques	COAL 1 is an integration feedback model of the system dynamics variety developed by Jay W. Forrester at the Massachusetts Institute of Technology (see *Industrial Dynamics*, M.I.T. Press, 1961). The model consists of a set of equations expressed in the level-rate format of the DYNAMO simulation language. Nearly all input variables are endogenous to the overall model boundary, with the exception of foreign energy prices and domestic energy demand. Sensitivity analyses and policy evaluations are normally undertaken through simple changes in parameter values or in the tabularly expressed values of many model relationships. Several reference runs replicating the historical behavior of the whole US energy system, as well as individual sectors, have been completed. A variety of sensitivity and policy runs have also been conducted.
Input Data	Where available, COAL 1 employs cross-section, time-series, and other statistical evidence to formulate parameters, tabular relationships, and structural assumptions. Known relationships for which hard data are unavailable have been formulated by representation of "best-guess" estimates in tabular form. "Best-guess" estimates have been based on descriptive information obtained from expert opinion and from published sources.
Output Data	The model prints both tabular and graphic output in response to a run command. The two forms of output, available for both physical and financial variables, are recorded at previously designated intervals of time throughout a given run.
Observations	The model behavior to date suggests that no supply strategy can prevent either massive dependence on foreign imports or serious supply shortfalls before the year 2000, unless the growth rate of domestic energy demand drops significantly. Moreover, coal is preferable to nuclear power as an interim transitional fuel through the year 2010.

BELGIUM

The Model	Study of the optimal structure of the Belgium refining industry. (B401) Franz Jomaux, Faculté Universitaire Catholique de Mons, 151, chaussée de Binche, 7000 Mons.
Subject and Goal	The model studies the optimal structure of the refining industry in Belgium with a view to determining an optimum long-term investment program, including the spatial repartition of equipment.
Modeling Techniques	Linear programming. The objective function is to minimize the total cost of transporting principal refined products to the place of consumption; total cost includes purchasing cost of crude, transport cost of crude by pipeline, refining cost, and transport cost of finished products. The constraints are: regional demands, technical refining constraints, the crude supplying structure, and quality standards for refined products. The variables are divided into primal: capacities of units to be set up in the various refining centers (strategical variables), and working rules of the various refining centers and distribution plan of refined products (tactical variables); and dual: marginal costs of finished products in the refining centers and in the consumption areas, and marginal costs connected with other constraints of the model.
Objectives	The study is the subject of a thesis outlined as follows: introduction and problem definition; description of the refining industry in Belgium; model of the refining industry (the model is of a single refinery with a spatial submodel including several refineries and their junctions with consumption points of a given area and a multiperiod submodel to tackle the seasonal demand variations); solution of the models on computer (matrix generation and LP code utilization); application of the spatial and multiperiod models to the Belgian situation of 1971; forecast of the optimal structure of the refining industry in Belgium for 1980 and 1985; and conclusions.

MODELS CLASS B

CANADA

The Model		Optimal sales policy for Canadian natural gas. (CDN401) Ross C. Richards, Energy Models Division, National Energy Board, Ottawa
Subject and Goal		To maximize discounted profit subject to Canadian requirements, US contract demands, export surplus calculation requirements, and pipeline capacity and/or deliverability constraints.
System Description		The model describes a linear programming allocation scheme from six supply areas to three markets maximizing discounted profit.
Area	Time	For each year, 1972-2000.
	Space	For Canada and the USA.
Modeling Techniques		Linear programming. The model is set up to handle multiple time periods, using either yearly or multiyearly data. Variations in the surplus calculation are handled easily through the matrix generator.
Input Data		-Cost of natural gas from each of the supply regions; -Selling price of natural gas in each of the demand regions; -Discount factor to be used in each period; -Canadian demand that must be satisfied; -US demand that must be satisfied; -Capacity and/or pipeline constraints from each of the supply areas; -Natural gas reserves in each of the supply areas; -Form of protection formula that will be used to calculate an exportable surplus.
Output Data		-Run number, data source, protection formula used, date of run; -Sales in each period; -Pipeline potential and capacity throughputs; -Reserves available, protection needed, and surplus available for each period; -Cost, price, profit and discounted profit for each period in each demand region; -Both total profits and unit profits for each source for each demand region, both discounted and undiscounted; -Total optimum profit.
Observations		A similar model also exists for crude oil. The main feature of the model is the handling of the surplus calculation using various formulae. The model includes a matrix generator, an out of core solution technique and a report generator which produces readable results easily.

MODELS CLASS C

TURKEY

The Model		Energy system planning mini-model. (T401) I. Kavrak, The Energy Group, Boğaziçi University, Istanbul, Turkey.
Subject and Goal		The goal of the model is the planning of the energy sector. The optimal investment policy is determined, with the objective of maximizing overall energy utilization efficiency, or minimizing cost.
System Description		The system describes a network of energy converters grouped into three classes: primary, intermediate, and final conversions. Energy flows from sources, through converters, to the demand nodes. The variables (~140) are the energy flows in the network, and the aggregated capacities of all production and distribution plants at each time period.
Area	Time	A time horizon of 15 years, with intervals of three years.
	Space	The energy economy of Turkey.
Modeling Techniques		Linear programming model. The model's dynamic character is incorporated by linking each time interval to preceeding ones through decision variables. The rows (~200) are: energy flow balances; and demand, capacity, capacity consistency, reserve, budget, and foreign funds constraints. The objective function(s) can be any one or a combination of the following: minimum cost, minimum primary energy, and/or maximum utilized energy.
Input Data		The model parameters are as follows: -Coefficients of energy conversion for all transformations of energy from one form into another, as well as those for transport and distribution; -Local and foreign components of the unit investment costs of all energy converters; -Prices of all fuels; -Reserves of indigenous energy sources; -Capacities of existing plants. Constraint coefficients for demand, budget, and technology are also supplied to the model.
Output Data		The output data corresponding to the variables defined above are as follows: -Amount and type of primary energy supplied to all plants and sectors at each time interval; -Amount and type of secondary energy generated at each plant at each time interval; -Amount of energy utilized by each demand sector at each time interval; -Amount of local and foreign funds spent at each time interval; -New capacity added at each time interval.
Observations		The model has been applied to Turkey for the period 1960-1975 in order to check the model's validity, and good results have been obtained. Results for the period 1976-1991 have also been secured. A much larger model of about ten times the size, and a modified mathematical structure are being developed.

USA

The Model	The energy supply planning model. (USA403) M. Carasso and J.M. Gallagher, et al., Bechtel Corporation, San Francisco, California, 1975.
Subject and Goal	The model determines the time series requirements for specific physical and societal resources (capital, manpower, materials, and equipment) associated with the construction and operation of energy-related facilities needed to implement exogenously specified US national or regional energy programs in the 1976-1995 time frame.
System Description	A national energy model of the USA, with a highly disaggregated description of the energy supply system composed of 66 energy supply facilities and 25 energy transportation facilities required to recover, convert, process, transport and distribute fuels (10) for direct utilization by consumers. Each facility type is a building block or "nominal facility", with an associated extensive data base on physical and societal resources required to construct and operate. The model focuses on the impact on these physical and societal resources data, both at the national and regional levels, of the various combinations of technologies required to implement future candidate energy programs.
Area — Time	From 1973 to 1995 for fuels and facilities; from 1974 to 1985 for capital, manpower, materials, and equipment resources; annual time periods.
Area — Space	National (USA) with fourteen regions, three of which are offshore supply regions. Eleven inland regions map directly into a nine-region U.S. Census Bureau breakdown. Expansion into global scope possible.
Modeling Techniques	A simulation model based on engineering estimates of physical relationships. Special emphasis was placed on developing a rather transparent planning model that proceeds from user-specified assumptions for major variables through a series of easily understood submodels to produce capital, manpower, materials, and equipment resource requirement results. User access to major decision points within each submodel is deliberately emphasized so that the model results represent information derived from simulation of policy decisions rather than a decisionmaking capability provided by the model. The model proceeds from an exogenous time-phased energy mix to calculated annual schedules of energy supply facilities required to come on-line. Based on user specifications, it locates the facilities in one of fourteen supply regions, allocates fuel derived from the facilities to the demand of the eleven land regions, and calculates transportation facilities required to accomplish this distribution. Finally, it calculates the annual requirements of capital, manpower, material, and equipment for each supply and transportation facility from initial commitment to plant startup and for operation throughout its economic life, for each fourteen regions and the country as a whole.
Input Data — User Specified Data	User inputs control the major decision variables of the model; default values exist to supplement user inputs. These inputs are as follows: future energy mix, typically for the years 1977, 1980, 1985, and 1990; retirement rates for existing facilities; energy facility location coefficients; regional fuel demand coefficients; regional fuel balancing rules; and interregional transportation facility modal split coefficients.
Physical Model Data	An extensive construction and operation data base has been developed by Bechtel Corporation on capital, manpower, materials, and equipment requirements for 91 energy-related facilities. For capital, there are 23 categories of data (two digit Bureau of Economic Analysis accounts); for

Input Data Physical Model Data (continued)	manpower, 27 categories of engineers, craftsmen, and others; and for materials and equipment, 27 categories of major items that may significantly inhibit energy construction programs. In addition, similar but less detailed categories of operations data are included. However, the operations data are neither designed to be nor are they sufficient to establish full operating costs. Another category of data included in the model is energy system data, e.g., facility definitions (capacity, heat rates, thermal efficiencies, etc.); transportation system data (haul lengths, number of trips/year); and interregional distance.
Ecological Model Data	Provision has been made for including annual requirements for land, water, air, and water pollutants for the 91 energy-related facilities. However, the ecological data have not yet been incorporated into the model.
Output Data Physical	The data requirements are as follows: -Annual schedules of required startup schedules for 91 energy-related facilities, nationally and in 14 regions, for the period 1976-1995 (also commitment schedules nationally); -Flows over time that balance regional supplies and demands of fuels; -Schedules of capital, manpower, materials, and equipment: annually for 1976-1985, for construction and operation, for each of the 91 facilities (and for whole system), and for each of 14 regions (and for whole country) for 1976-1985.
Ecological	When the data are incorporated, they can provide the annual volumes of land and water requirements and effluent emissions.
Observations	The model couples development and organization of an extensive current industrial data base into a framework that gives the policymaker flexibility to test the sensitivity of national or regional total resource requirements to broad changes in energy policy variables. The model will help to study the feasibility of various energy policies, their implications, and their desirability. The model is being used in policy applications, and it is under continuing modification and development. Additional areas being considered are extension to a longer-range time horizon, disaggregation of the regional planning capability to the state level, and extension of the spatial boundaries to a global model.

MODELS CLASS E

UK

The Model		Model for estimating price increases due to higher costs of petroleum and other imports.* (GB402) E.W. Henry and S. Scott
Subject and Goal		The model calculates the effect on sectoral prices of a rise in the price of imported fuels, especially oil, given certain assumptions.
System Description		The model covers 33 sectors of the economy in an input-output framework.
Area	Time	A static model that calculates the effects of fuel price rises in 1973/74.
	Space	Ireland.
Modeling Techniques		Input-output price model.
Input Data		The 33 sector 1968 input-output table for Ireland was disaggregated to give more detail, namely an "oil refining" sector was constructed, transport was disaggregated into five types of transport, 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 and the new costs of final demands (e.g., the new cost of living) are given.
Observation		The model can only account for rises in price resulting from rises in costs, and cannot take into consideration demand-pull type price rises.

*A description of the model appeared in the *Quarterly Economic Commentary* (March 1974), published by the Economic and Social Research Institute, Dublin, Ireland.

NEW ZEALAND

The Model	A planning model of New Zealand's energy industry. (NZ401) B.R. Smith, P.D. Lucas, B.A. Murtagh, Victoria University and Ministry of Energy Resources, Wellington.
Subject and Goal	The modeling objective is to formulate proposals for satisfying the country's forecast energy demands, subject to various technical and environmental constraints. These proposals specify the optimal fuel mix, capacities of the process plants and generating stations in the system as well as the energy resources required. The optimality criterion is usually that of least cost, but this can be altered. The model is to be used by the government energy planning agency (the Ministry of Energy Resources).
System Description	The model describes the annual operation of the country's energy system for various target years. It considers a wide range of energy sources, energy conversion processes, and utilizing devices. Energy demand is disaggregated into eleven consumer categories for each of two demand regions. The infrastructure of the energy system is taken into account as are the various distribution networks available to the energy industry.
Area — Time	Static model for a particular target year. (To date the model has been applied to 1985, 1990, and 2000.)
Area — Space	New Zealand as a whole.
Modeling Techniques	Optimization model using linear programming and, less frequently, nonlinear programming. The energy system is represented by sectoral submodels, some of which can be implemented separately. The following submodels are specified: electricity conversion; oil refinery; natural gas refinery; coal submodel; and distribution. These submodels, integrated with a demand structure, make up the LP model of the energy system. The LP formulation consists of 380 rows and 885 variables. Use is made of a matrix generator/report writer language to facilitate model construction and the presentation of results.
Input Data	For any given target year the input consists of approximately 3000 data elements; many of these are fixed for each year. The major parameters are: -bounds on energy resource availabilities; -bounds on capacities of units in the conversion processes; -levels of end-use consumer demand for each of the categories considered; -the infrastructure of the energy system; -coefficients of conversion and distribution losses; -costs of energy resources; -amortized capital costs and maintenance costs of both processing units and utilizing devices. Generally it is only for the first four classes of parameters that data values change from year to year.
Output Data	-Levels of each energy resource used; -The operation of the conversion and distribution processes in the energy system; -Optimal capacities of the process units and utilizing devices; -The quantity of each type of fuel supplied to both end-use and intermediate demands.
Observations	Reactions to the model suggest that it embodies sufficient detail, and still retains enough conceptual simplicity for the energy planners to be confident of using its results.

MEXICO

The Model		"Mexico"--national energy model. (M401) J. Lartigue G., University of Mexico, Cd. Universitaria, Mexico, D.F., 1976.
Subject and Goal		The model forecasts both the energy supply and demand up to the year 2000, and the probable structure of a hydrogen-economy-based generation.
System Description		The model is concerned with the following: -The energy sector of Mexico, including national reserves; -The most probable development of the energy demand and its influence on the fertilizer industry; -The probable structure of the energy production, based on a hydrogen-economy, including nuclear and other new sources.
Area	Time	1974-2000.
	Space	Mexico.
Modeling Techniques		-Analysis of the energy sector in 1974; -Statistical analysis of the development of population, gross national product, and energy consumption in order to forecast future energy demand; -Calculation of the energy content of national reserves; -Future model divided into natural resources, processes, products, and end uses illustrating qualitatively the relationship between them.
Observations		Since the model is not quantitative, costs of energy are not explicitly considered.

SWEDEN

The Model

An energy forecasting model for Sweden. (S401)

Lars Bergman, Clas Bergström, Anders Björklund, Economic Research Institute at the Stockholm School of Economics. The National Swedish Industrial Board uses the model in connection with the long-term energy projections and analysis. Clas Bergström, Mats Hüjeberg, and Georg Saros at the Energy Division are responsible for the implementation and development of the model.

Subject and Goal

The model investigates how the allocation of energy resources in the Swedish economy is likely to develop under various assumptions about primary energy prices, technological change, and overall economic and energy policy.

System Description

The model has the following properties:
- The model solution is based on explicit assumptions about prices of different kinds of primary energy, the availability of technology, and the choice of strategy for implementing long-term policy goals.
- The time horizon of the predictions is semi long term, that is, a time period long enough for various substitution processes to take place, but short enough that no fundamental change in the energy transformation technology could occur.
- A consistent treatment of current production, that is, in every model solution there should be a balance between the supply and the demand for each commodity group.
- A consistent treatment of investment, that is, in every model solution there should be a balance between gross savings and gross investments, with consideration given to both the demand and the capacity creating aspects of investment.
- A proper treatment of prices, that is, the role of prices in the choice of technology and in the composition of final demand should be recognized.

Thus, the model allows for ample substitution of 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 five-year interval between each year, up to the year 2000.

Space: Sweden as a whole.

Modeling Techniques

Within a general equilibrium framework a number of submodels have been linked to a linear activity model based upon input-output data. These submodels are either econometric or programming models and utilize both observed and engineering data. These submodels are as follows:

a) The supply model for electricity and hot water is a linear programming model in which the present value of the total costs of meeting exogenously determined demands are minimized. The model utilizes engineering data.

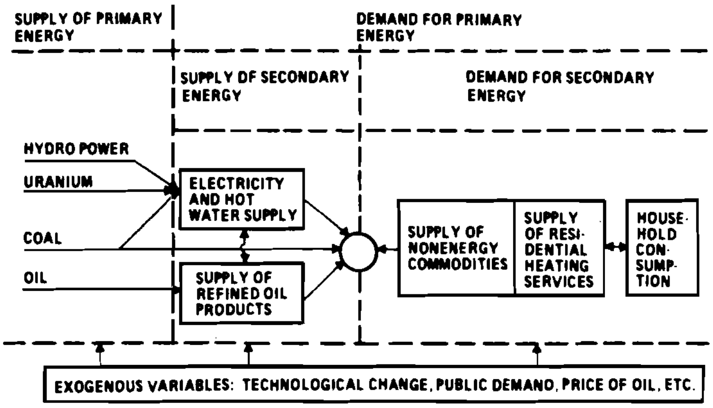
b) The supply model for refined oil products is also a linear programming model utilizing engineering data. The criterion to be minimized is the same as in the electricity and hot water supply model.

c) The nonenergy commodity supply model is a multiperiod linear activity model based upon input-output statistics.

d) The residential heating model is similar to models a) and b).

e) The household consumption demand model is a so-called complete system of simultaneous demand equations, based upon observed data and estimated by means of econometric methods.

The figure below shows the general structure of the model.



MEXICO

The Model		"Mexico"--national energy model. (M4O1) J. Lartigue G., University of Mexico, Cd. Universitaria, Mexico, D.F., 1976.
Subject and Goal		The model forecasts both the energy supply and demand up to the year 2000, and the probable structure of a hydrogen-economy-based generation.
System Description		The model is concerned with the following: -The energy sector of Mexico, including national reserves; -The most probable development of the energy demand and its influence on the fertilizer industry; -The probable structure of the energy production, based on a hydrogen-economy, including nuclear and other new sources.
Area	Time	1974-2000.
	Space	Mexico.
Modeling Techniques		-Analysis of the energy sector in 1974; -Statistical analysis of the development of population, gross national product, and energy consumption in order to forecast future energy demand; -Calculation of the energy content of national reserves; -Future model divided into natural resources, processes, products, and end uses illustrating qualitatively the relationship between them.
Observations		Since the model is not quantitative, costs of energy are not explicitly considered.

SWEDEN

The Model

An energy forecasting model for Sweden. (S401)

Lars Bergman, Clas Bergström, Anders Björklund, Economic Research Institute at the Stockholm School of Economics. The National Swedish Industrial Board uses the model in connection with the long-term energy projections and analysis. Clas Bergström, Mats Hüjeberg, and Georg Saros at the Energy Division are responsible for the implementation and development of the model.

Subject and Goal

The model investigates how the allocation of energy resources in the Swedish economy is likely to develop under various assumptions about primary energy prices, technological change, and overall economic and energy policy.

System Description

The model has the following properties:
-The model solution is based on explicit assumptions about prices of different kinds of primary energy, the availability of technology, and the choice of strategy for implementing long-term policy goals.
-The time horizon of the predictions is semi long term, that is, a time period long enough for various substitution processes to take place, but short enough that no fundamental change in the energy transformation technology could occur.
-A consistent treatment of current production, that is, in every model solution there should be a balance between the supply and the demand for each commodity group.
-A consistent treatment of investment, that is, in every model solution there should be a balance between gross savings and gross investments, with consideration given to both the demand and the capacity creating aspects of investment.
-A proper treatment of prices, that is, the role of prices in the choice of technology and in the composition of final demand should be recognized.

Thus, the model allows for ample substitution of 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 five-year interval between each year, up to the year 2000.

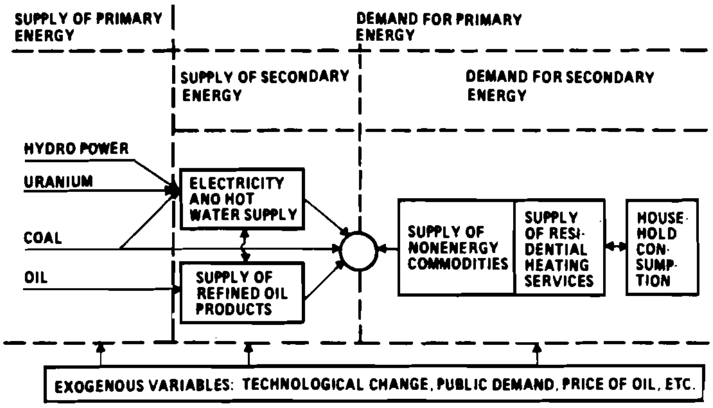
Space: Sweden as a whole.

Modeling Techniques

Within a general equilibrium framework a number of submodels have been linked to a linear activity model based upon input-output data. These submodels are either econometric or programming models and utilize both observed and engineering data. These submodels are as follows:

a) The supply model for electricity and hot water is a linear programming model in which the present value of the total costs of meeting exogenously determined demands are minimized. The model utilizes engineering data.
b) The supply model for refined oil products is also a linear programming model utilizing engineering data. The criterion to be minimized is the same as in the electricity and hot water supply model.
c) The nonenergy commodity supply model is a multiperiod linear activity model based upon input-output statistics.
d) The residential heating model is similar to models a) and b).
e) The household consumption demand model is a so-called complete system of simultaneous demand equations, based upon observed data and estimated by means of econometric methods.

The figure below shows the general structure of the model.



Input Data	Physical	The description of power stations, refineries, and house-heating systems is based upon engineering data; 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 general solution all prices (except those of energy resources) are endogenous. To close the system, different assumed price paths for primary energy, capital, and labor are used.
Output Data	Physical	The model forecasts Sweden's future use of energy resources subject to prices of energy resources, the energy policy, and technological change in the energy supply sector.
	Economic	The model forecasts a path of energy prices in a state of equilibrium.
Observations		The household consumption model has been estimated with ten commodities. Within the limited framework of this submodel we have studied the sensitivity of allocation of private expenditure to changing energy prices. The linear programming submodels a, b, c, and d have been used to analyze resource allocation problems within each of these sectors.

MODELS CLASS F

JAPAN

The Model	A simulation model for a study of the dynamic behavior of crude oil production in Middle East oil exporting countries. (J401) Teruyasu Murakami, Nomura Research Institute, Japan, 1973.
Subject and Goal	The modeling objective is to study the behavior of crude oil production of Middle East oil exporting countries and to identify the effects of the alternative long-term economic and energy policies of consuming countries.
System Description	The model covers the international flow of oil and money between oil exporting countries and oil consuming countries. For the oil exporting countries, the following factors are considered: crude oil production, energy prices, government oil revenues, government budget, economic and social development investments, industrial development, infrastructure development, economic growth, population, petrodollars. For the oil consuming countries, the following factors are considered: economic growth, energy demand, conventional sources of energy, new sources of energy development, crude oil demand and supply gap, and oil balance of payment. The level of crude oil production influences the economic and energy policymaking in oil producing countries.
Area — Time	1965-1985.
Area — Space	Iran, Saudi Arabia, Kuwait and other Middle East oil producing countries, and Japan, the USA, and the European countries of the Organisation of Economic Cooperation and Development (OECD).
Modeling Techniques	A dynamic system simulation model using DYNAMO II. For the "hard" part of the system, regression equations based on relatively reliable statistical data are used. The "soft" part includes information compiled from reports of economists, engineers, government officials based on research and interviews in some OPEC countries and in Japan.
Input Data	Input data include annual growth rate of GDP in each consuming countries; growth rate of the export price index of industrial commodities in OECD countries; energy supply from tar sand, shale oil, gasificated coal, liquid natural gas, methanol, nuclear energy; average capital output ratio; government participation ratio to oil industries of oil exporting countries.
Output Data	Output data include crude oil production; government oil revenue; government expenditure by recurrent, development and military budget; oil exports; non-oil exports; producers' goods imports; consumers' goods imports; GDP of Iran, Saudi Arabia and Kuwait; energy supply by various energy sources; oil imports; accumulation of deficit of current and basic account with oil exporting countries; crude oil demand supply gap of consuming countries.
Observations	Since the model has only three country submodels of Middle East oil exporting countries, there is a need to increase the number of country submodels. Reliable statistics of oil exporting countries have not been utilized in the development of the models. More disaggregation of each country submodel is expected.

EUROPEAN COMMUNITY

The Model		Evaluation of power station installation policies. (XX401) F. Conti, G. Graziani, C. Zanantoni, Commission of the European Communities-JRC-Ispra (Varese), Italy.
Subject and Goal		The model describes the consequences of alternative power station installation policies which satisfy a given electrical energy demand and load duration curve. The installed power of the various power plant types is obtained as a function of time. Fuel consumption and services are calculated as are investment and running costs.
System Description		The model deals with the evolution in time of the electrical power system. In particular attention is focused on the mix of power plants that satisfies the given electrical energy and load demand. The yearly electric energy demand over the period considered is given as input. The load diagram of the demand is also given; its shape can change during the period under investigation, both because of a change in the consumption spectrum and because of the development of some types of energy storage: a maximum of five load diagrams are foreseen corresponding to five time intervals. The plants are subdivided according to a number of age groups (a maximum of ten) affected by different maximum utilization. Age groups are grouped in sets on which the allocation procedure of the stations in the load diagram is based. The first group sets refer to the running-in period, when the stations are not able to work at their maximum numerical utilization. The intermediate group sets refer to the equilibrium period and usually cover the largest fraction of the plant life. The last group-sets are relative to the running-out period of the plant life, when the station's availability decreases. The energy produced by each plant type is given as an input explicitly or calculated on the basis of the constraints imposed to the system. The two main constraints are the generating capacity doubling time, accounting for the difficulties of the industry in coping with a rapid increase of production; and the availability of artificial fissile material such as Plutonium or Uranium-233 produced by other nuclear stations.
Area	Time	30 to 55 years
	Space	The European Community as a whole.
Modeling Techniques		This is a simulation model programmed for the IBM 370/165 computer in Fortran language (TOTEM computer program). In a certain year N the program, using the input data and the results of calculation of the previous year, proceeds as follows: -It allocates "unavoidable" plants in the load diagram. The area corresponding to these plants is subtracted from the load diagram. As a result, the load diagram shape for the competitive plants is modified. -It allocates the existing competitive plants into the modified load diagram. Due to the age-factor history, the maximum energy produced by the existing plants changes every time-step. The allocation procedure has to be repeated each year. The allocation procedure is carried out starting from the peak toward the diagram base. This is possible by assuming that any new plant works at base-load during the first year of its life. Once this step is completed, a check on the fuel requirements is performed. -Determination of new plant installation needs. If necessary, new plants are installed according to the energy needs. At the end of plant installation, the following steps are performed: calculation of the value of the reserve, and calculation of the energy required by the pumping stations. Once the calculation of the whole period under investigation has been completed, the energies and power capacities of all plant types are known for every year. Fuel demands and productions, relative to inventories and energy production, and the costs can thus be determined.
Input Data		For each type of power station the physical and economical characteristics are given, e.g., fuel consumption, fuel inventory, plant cost, fuel fabrication and reprocessing costs, and such delays as mine enrichment, plant fabrication, plant storage, core residence, cooling, reprocessing. The cost of fuel can be constant or can vary with time.
Output Data		The code can perform many calculations, based on the basic evaluation concerning the number of power stations existing per year, type and age-group and their utilization hours it calculates. For each year can calculate the consumption of various types of fuel, the fuel inventory due to new installations, and running costs, and capital investments. The expenditures can be actualized, the discount rate being one of the input data. Taking into account the various delays, the code evaluates the ore requirements, the separative work and consequently the enrichment plant capacity required, the capital investments as a function of time, etc.
Observations		The model takes no account of location problems of plants and consumption centers and of related transmission and distribution problems. A separate model has been developed for this purpose which can be used in parallel with TOTEM (SITUS computer program).

UK

The Model	Demand for energy forecasting model. (GB401) G. Kouris, University of Surrey, Guildford, Surrey, England, 1975.
Subject and Goal	The aim of the study is to build an aggregate energy demand model on economic a priori criteria. The inadequacies of small samples and time series data are overcome by considering the EC as one country with a number of geographically different provinces (member countries). This assumption yields more realistic estimates of the major determinants of energy demand. These, in turn, are used for forecasting the energy requirements of the entire EC area in the year 1980.
System Description	The consumption of primary fuels in eight Common Market countries is pooled in order to obtain one set of homogeneous demand elasticities. The main short run determinants of energy demand are: income, price, and temperature. Since the model is applied on a pooled sample its time specification applies to the intermediate run. A detailed subdivision of this sample reveals a number of structural problems which make the stability of the model over time a function of these problems.
Area — Time	Econometric estimates for the period 1955-1970. Test of the predictive power of the model up to 1974 and forecasts up to 1980.
Area — Space	Italy, Netherlands, Denmark, France, FRG, Belgium/Luxembourg, UK.
Modeling Techniques	Econometric techniques. The main equation of the model is firstly tested on time series data for each EC country and secondly, a covariance transformation of it is applied on a pooled time series--cross sections sample. The possible feedbacks from energy to GDP are investigated through a two equation model where the energy function is supplemented by a production function of the Cobb-Douglas type. This formulation is estimated via a two stage least squares technique. All equations are linearized by a double logarithmic transformation.
Input Data	Time series of quantities (in metric tons of coal equivalents), incomes (GDP), relative fuel prices, average yearly temperatures, and number of employees in employment, for each EC country over the period 1955-1974.
Output Data	Income, price, and temperature elasticities for each country and for EC in total. Test of the stability of the energy function for the "crisis period" 1971-1974 and forecast of the 1980 EC energy requirements.

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