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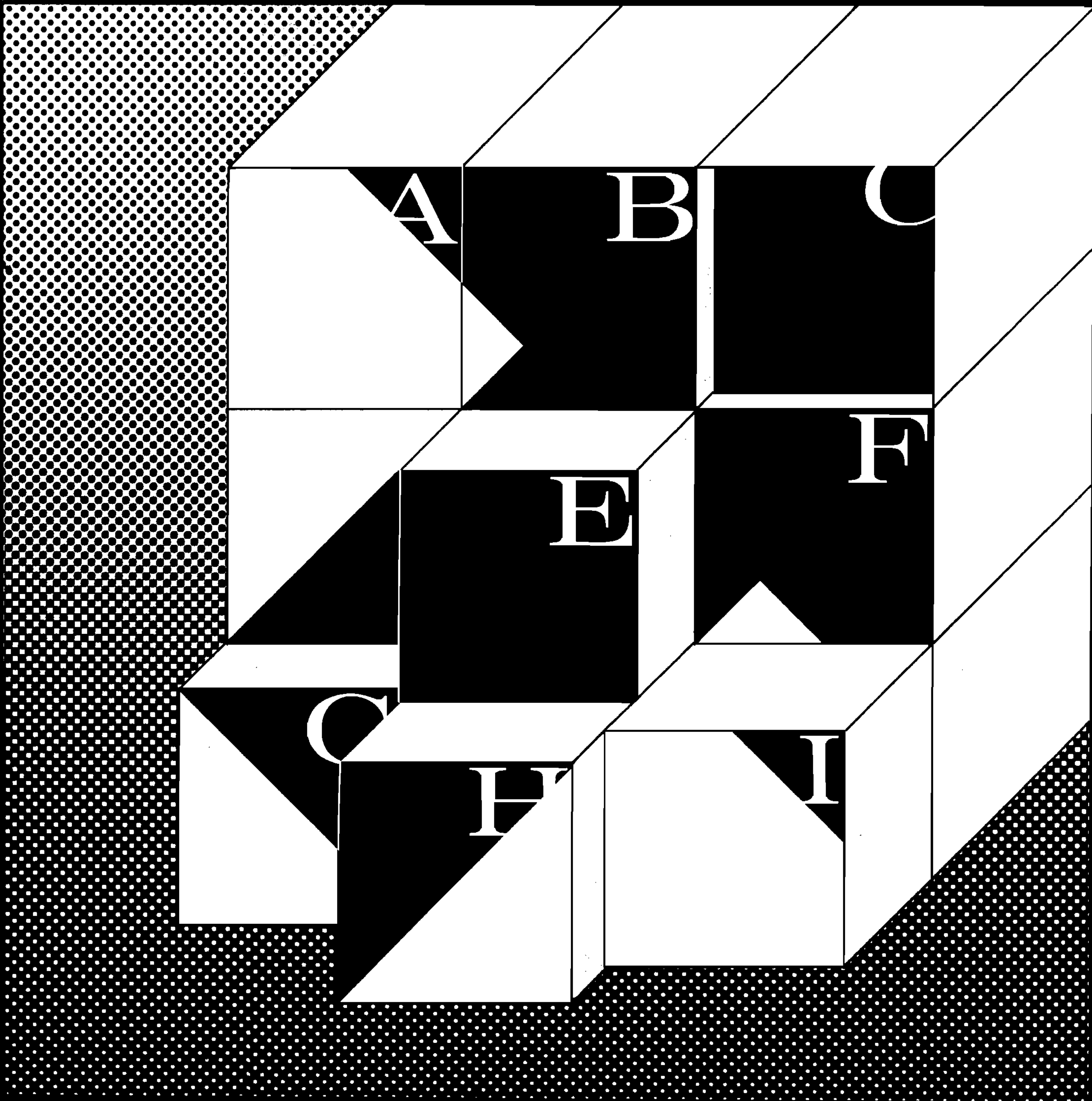

A REVIEW OF ENERGY MODELS

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SPECIAL ISSUE ON SOVIET MODELS

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Preface

In this third review, Soviet energy models are presented. This entire work is the result of a fruitful collaboration between three Soviet energeticians: L.S. Belyaev, Yu.D. Kononov and A.A. Makarov, who at their home institute in Irkutsk* actively participate in energy modelling. We are pleased with this initiative on the part of our Soviet colleagues at IIASA.

The format of this third review has to some extent changed; it not only gives detailed descriptions of each model but provides, in Part I, the philosophy and mode of approach--which varies from one country to another--for better understanding of the peculiarities of the models described. This conceptual framework gives a more accurate picture of how models are used. In order to preserve the meaning of this analysis, which is self-consistent, we have made only minor editorial changes in the original work.

Let us make a few comments on the models presented. The energy economy is approached comprehensively, from the production of energy sources to the demand of consumers. Second, the energy system is embedded in the socioeconomic stratum. The doctrine is that there exists an energy supply system that is a combination of industries catering for *society's manifold energy needs*. Then, the models presented are peripheral to the macromodels of Gosplan, which produce the optimal price structure of the entire economy. These prices and constraints are used as input in the peripheral models which give the optimal production. This is fundamentally the same approach as used by Jorgenson**: A macrogrowth model provides prices, capital and labor which serve as input to the input/output matrix whose coefficients are dependent on the relative price structure. Finally, linear programming is the main technique employed; we regret that no model is included that uses optimal control theory, in which Soviet experts have great experience.

In conclusion, we hope that readers will profit by the vast experience gained in modelling energy systems development in the USSR, and that other National Member Organizations (and other countries) will provide our review series with comprehensive reports on models and their institutional context.

The Editors

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*Siberian Power Institute of the USSR Academy of Sciences, Irkutsk.

**E.A. Hudson and D.W. Jorgenson, *Review of Energy Models No. 2*, RR-75-35, IIASA, 1975, p. 91.

METHODS AND MODELS FOR OPTIMIZATION OF ENERGY SYSTEMS DEVELOPMENT: SOVIET EXPERIENCE

L.S. Belyaev, Yu.D. Kononov, and A.A. Makarov

Summary

The experience of the USSR in the field of energy systems development modelling reveals certain patterns and principles that influence the structure and use of energy models, principally:

- The need to use mainly optimization models since, for planning purposes, optimal solutions must be found;

- The need to coordinate individual models in order to obtain the country's objectives;

- The existing organizational structure of planning which must be taken into account;

- The dependence of models on time aspects of planning (annual, 5-year, 15-year);

- The elaboration of corresponding methods for providing necessary input data.

This has required the development of a special concept for optimizing energy systems development with the use of mathematical models. It is based on consideration of the energy industries of the country as complex with a hierarchical structure of energy systems of various territorial and branch levels. At the same time, the differentiation of aims at different times during the planning period have been taken into account.

This concept is given here in its existing state (it is continuously developed and perfected) for better understanding of the energy models described. In particular, we show the role of the system of models for optimization of the energy supply system as a whole, and that of more detailed branch models (oil, gas, coal, electricity production systems).

For optimal energy strategy evaluation, the most important models are those used on the highest levels of the energy systems hierarchy, i.e. the general (aggregate) energy systems of the country and of economic regions, and branch energy systems. Only these models are described here; models used on lower levels for solving some technical problems are far more diverse and numerous, and it is impossible to consider them all in a single review.

Methods and Models for Optimization of Energy Systems Development: Soviet Experience

L.S. Belyaev, Yu.D. Kononov and A.A. Makarov

Part I: Methods

INTRODUCTION

Two reviews of energy models have been issued by IIASA [1,2]. They point to a recent trend towards modelling the energy industries as a whole rather than taking into consideration individual kinds of fuel and power.

Since 1962, a comprehensive approach to energy systems modelling has been elaborated in the USSR under the guidance of Academician L.A. Melentiev [3]. Basically, it comes down to consideration and modelling of the energy economy as one complex process encompassing all the partial processes of conversion of energy resources from source to consumer; thus each separate unit is examined and managed with due regard to its influence on neighboring units, rather than in isolation.

This review reflects the experience in the field of optimization and modelling of energy systems development in the USSR. It gives a summary description of: the concept of optimization of the energy system of the USSR; the principles of energy systems modelling and the basic phases of its development in the USSR; the system of models for optimization of energy systems development; and the principal mathematical models used at present in the USSR to optimize the energy system and its major subsystems.

CONCEPT OF ENERGY SYSTEMS OPTIMIZATION

A doctrine of centralized planning of the national economy has been put into effect in the USSR, which views the economy as one system. For energy systems, this doctrine is embodied in the concept that there objectively exists a energy supply system (ESS), which is a combination of industries catering for society's manifold energy needs. Since the early thirties, the school of Academician G.M. Krzhizhanovsky has put forward the idea that energy economy should be approached comprehensively: from production of energy sources to consumers. This view has largely affected the methods and organization of plans for energy systems development and has provided the methodological basis for the subsequent correct statement of problems in optimizing the ESS.

One of the axioms of the systems approach is that the composition, type and basic characteristics of a mathematical model are determined by the nature of the problems they are to solve and by the organizational structure of management. We must therefore give at least a brief description of the organization of ESS planning in the USSR, for a better understanding of the mathematical models presented here. These models conform strictly to present-day planning practices. At the same time, using the systems approach, large-scale research and practical work are currently under way in the USSR to improve planning organization and to develop appropriate new mathematical models and optimization methods. This aspect will not, however, be reviewed here; certain phases of such work are described in [4].

The ESS in fact represents a hierarchy of energy systems of various territorial and branch levels. In somewhat simplified form this hierarchy is given in Figure 1. Branch systems of each territorial level (excluding plant level) form a general (or aggregate) energy system. Such a system is very important while the development of energy systems is being optimized. On the national level the general energy system represents the ESS as a whole.

The nuclear industry is only now developing. Therefore its structure and peculiarities on the regional and industrial center levels are not yet clear, and its systems are not shown in Figure 1.

The ESS, or fuel-energy complex, in the USSR is viewed as comprising the oil, oil-processing, gas, coal, peat, shale and nuclear industries, the centralized sector of electricity and heat production (electric power stations included in power systems or power districts, and large central boiler houses). It also functions as the distributer of all kinds of fuel and energy among industries, territorial regions, and major consumer categories. The complex includes appropriate construction organizations and some of the plants producing fuel and power equipment, as well as the main production units (mines, coal pits, coal concentration plants, gas and oil wells, refineries, gas and oil pipelines, electric power stations and power grids, central boilers, etc.).

The planning of the ESS is organized as a multilevel hierarchy, mainly by branch but partly also territorially, as illustrated in Figure 2. The top level of the hierarchy of planning for the energy industries is the USSR State Planning Committee (Gosplan USSR), which has the following functions: (a) ensuring optimum balance of production (including import) and consumption (including export) for all kinds of fuel and energy; (b) comprehensive elaboration and coordination of the principal items in the development plans of the energy industries, including final decisions on construction of large new power units; (c) allocation of capital investment, basic materials, equipment, and manpower resources, as needed by the energy industries and as can be afforded by the economy. Gosplan's decisions, after approval to the USSR Council of Ministers (Government) and the Supreme Soviet of the USSR (Parliament), become legally binding.

The next level of the hierarchy is the fuel and energy ministries whose responsibility is to organize (a) management of the industries concerned; (b) updating of the energy units in operation and the optimum design of new ones, taking into account the latest achievements in science and technology; and (c) drafting recommendations on the plans for industrial development, i.e. with regard to operation of existing energy units, construction of new ones, the capital investments involved, and the materials, equipment and labor requirements.

The main functional organs of a ministry are production bodies, usually organized on a territorial basis. They perform the main functions of a ministry with regard to the fuel and energy units in the region (but emphasizing economic management).

The official planning procedure in the USSR has three time planes: current (annual), medium-term (usually five-year), and long-term (10-15 years) planning. In addition, under the guidance of the State Committee for Science and Technology, research organizations compile regular forecasts of the nation's ESS development in a 25- to 30-year perspective.

Current planning is aimed at optimizing the use, in the current year, of the production capacities of the energy industries, so as to supply all sectors of the economy with an effective and regular flow of fuel and energy in keeping with their estimated rational needs. The annual plans also provide for specific measures aimed at developing the energy industries and making consumer use of fuel and power more effective, with a view to attaining the targets of medium-term planning. Supervision of plan fulfillment is another major function at this stage.

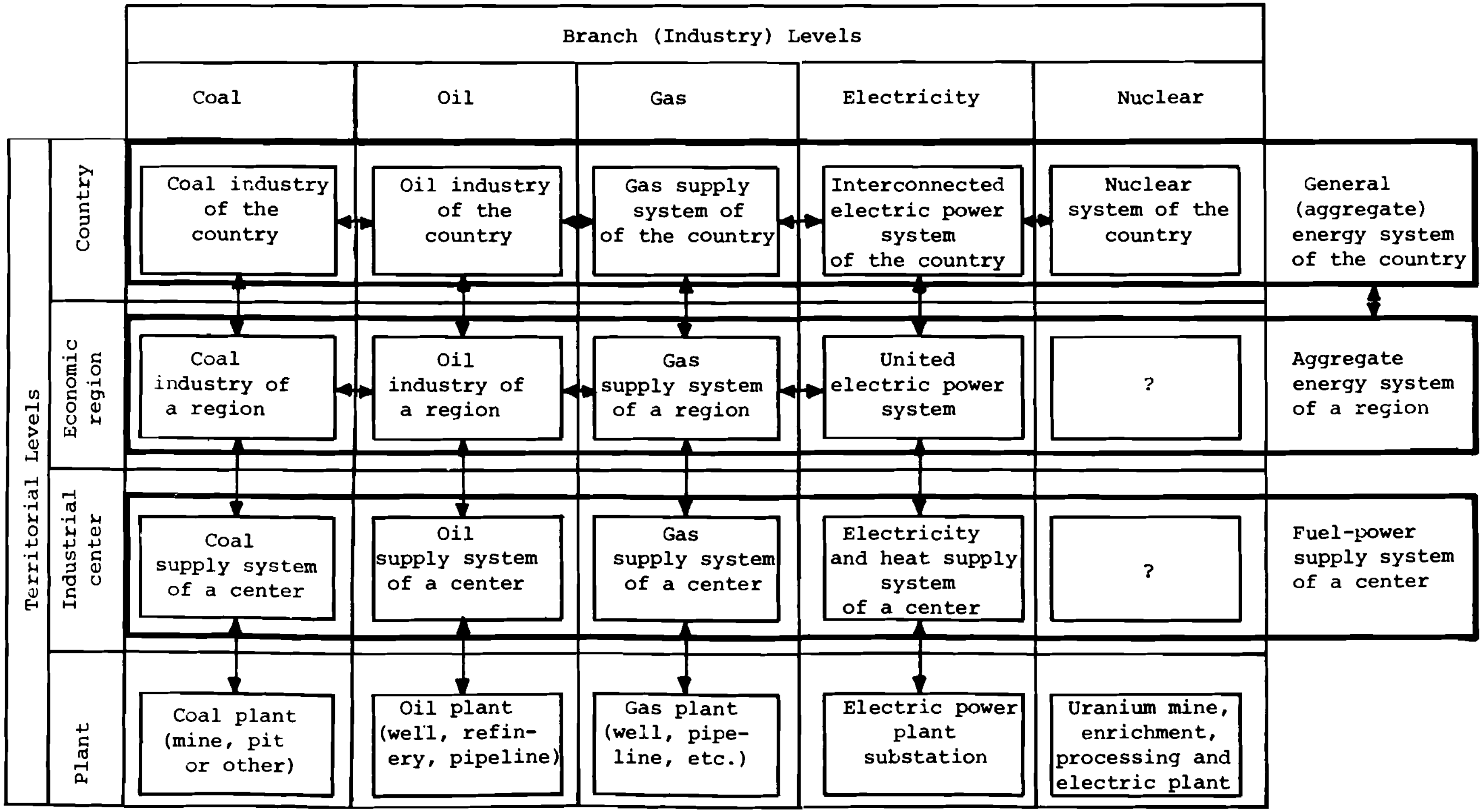

Figure 1. Energy systems hierarchy.

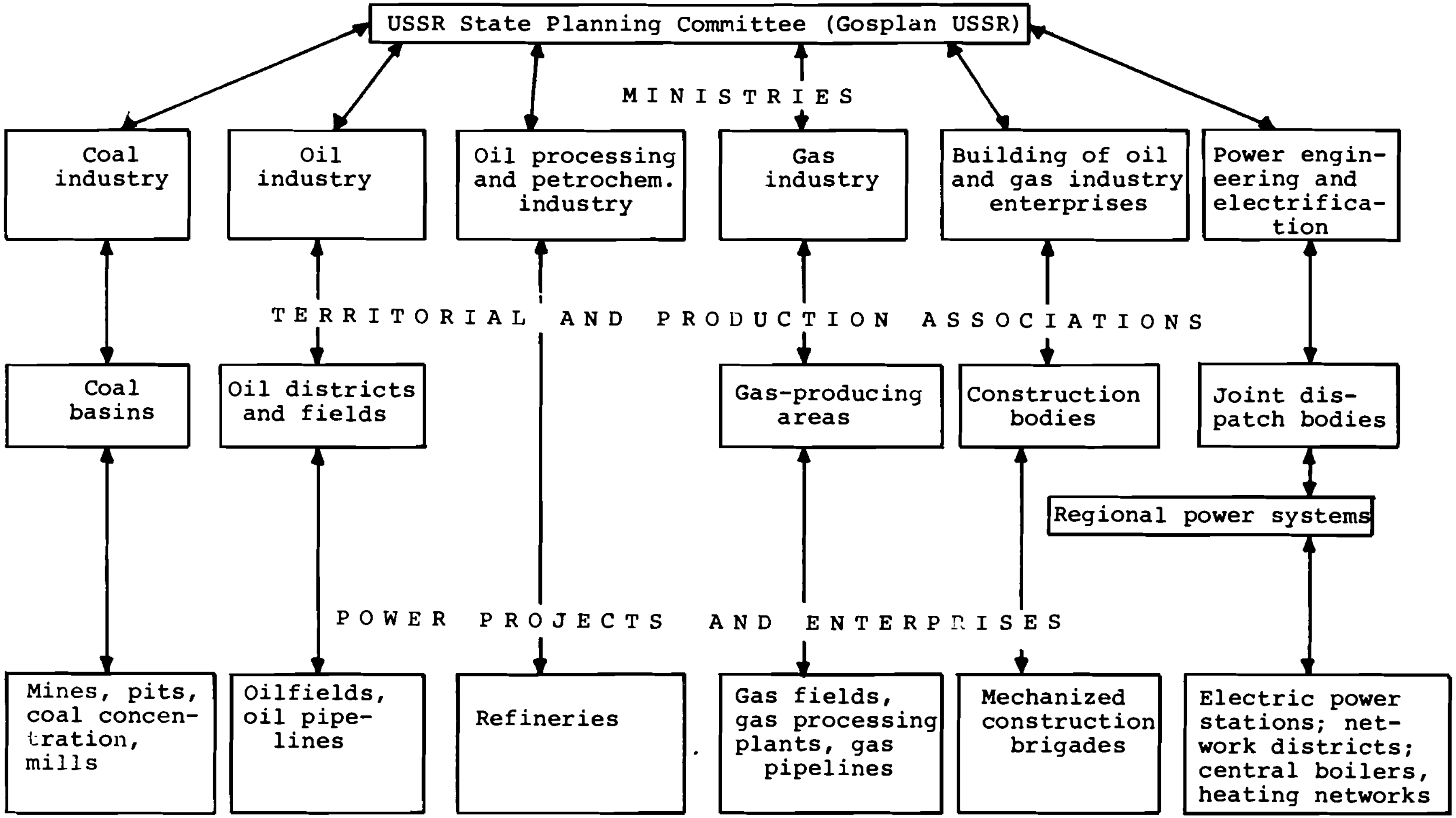

Figure 2. Aggregate scheme of organization for ESS planning in the USSR.

Medium-term (five-year) planning is the central stage in USSR planning. Its purpose is to set specific targets in developing the nation's economy and its sectors in the coming five years and to find the best ways of achieving these targets. For fuel and power, this means setting a reasonable rate for the development of the complex and its components, and determining the optimal production proportions as well as the composition, priorities, and terms for reconstruction and building of energy projects, taking into account the actual potentialities of the national economy to provide the complex with the necessary capital investments, materials, and labor resources.

Long-term planning is aimed at choosing the direction of future development of the economy, and in particular that of the ESS. Its main purpose is to facilitate the setting of medium-term plan targets and the assessment of those stocks and construction projects to be envisaged in the current five-year plan. Therefore, the long-term plans of the ESS are basically intended to determine the optimum location, productivity, construction times, and operation principles of large new power projects and to elaborate extensive programs that determine the main directions and technical level for the ESS. It is precisely at this stage that drastic structural changes in the development of the complex can be planned, since there is sufficient time for them to be implemented.

Forecasts for 25 to 30 years are made to elucidate and estimate the objective trends in ESS development. On this basis it becomes possible, with sufficient grounds, to choose the key lines of scientific and technological progress in power engineering; to identify the main problems involved and set out effective time terms for research on these problems; to determine a reasonable scale of development for the main oil and gas provinces and the coal basins across the country and estimate the material, labor and capital costs of developing new territories and geological prospecting; and to estimate, at least roughly, the subsequent efficiency of the principal measures envisaged in the long-range plans.

Each planning stage has its own specific degree of detailing the energy problems to be solved at that stage. Therefore, forecasting takes into consideration the ESS as a whole. In long-term and, especially, medium-term planning, decisions are taken for the whole hierarchy of systems (Figure 1), down to the energy-supplying parts of individual industrial units and plants. Accordingly, optimization problems have to be differentiated to a greater extent within the framework of the systems hierarchy of the ESS.

At each time stage, the planning of the energy complex, and of the national economy as a whole, is done in two steps. In the first step, the main trends in the development of the complex are established, i.e. the "control figures" are fixed (usually in the form of an interval) for the main products. These figures are given in an aggregate form, balanced in the input-output table of the economy, and harmonized with an accumulation fund of reasonable size and the available labor resources. At the second step, these control figures serve as the point of departure in drafting plans for the development of the complex. These include detailed plans for: production and investment; industrial implementation of scientific and technological achievements; labor, material, and technical supplies; reductions in cost, etc.

At each step, planning is done for all levels of the management hierarchy (Figure 2); proposals are submitted consecutively from lower to upper levels, and plan targets are transferred from upper to lower levels. Two "big iterations" are therefore needed in drawing up a plan, with all hierarchical levels participating. In addition, there are usually many "minor iterations" of coordinating plan proposals and solutions for adjacent hierarchy levels.

This planning scheme for the nation's ESS is labor-consuming and therefore calls for wide use of mathematical models and computers in order to automate the computation involved in elaboration of plan alternatives and their economic estimation and comparison. The accepted view in the USSR is that mathematical models, though necessary and efficient, are still only an auxiliary tool, allowing investigation of the possible trends and ways of development of energy systems, but inevitably leaving the final decision-making to the responsible executives.

Another basic principle in modelling the ESS is that the structure and complexity of the controlling system must correspond to the object being controlled. This means that a set (or system) of models is required whose structure would correspond to that of the hierarchy of the major energy systems and of the tasks of their optimization. The main models of this set are shown in Figure 3. The most important for ESS development planning is the complex of models for optimizing the general energy system of the country, and this complex is discussed below in more detail.

The third principle of energy systems modelling is the essential differentiation of models for various planning stages as regards a composition of blocks, the aspects of power production they describe in each case, and the degree of specificity. The reason for this is the difference between the groups of tasks being solved, as well as the need for simplified models to be applied to longer periods of time because of the rapidly growing error in input data.

If optimum directions and ways of development are to be chosen for the ESS, it must be considered dynamically, taking into account the discreteness of the projects and the nonlinear dependence of their investments on the final capacity. At the same time, the conditions of energy systems development can be predicted only approximately, and optimization should therefore be carried out in some uncertainty. As there are indeed very many energy units and, especially, consumers, the problem is highly multidimensional. Inevitably, the set of mathematical models for optimizing long-range energy development must have a multistorey structure, must be formulated in a dynamic statement, must take account of nonlinear-discrete properties of projects, and must admit of decision-making under uncertain conditions.

At the present state of computer and mathematical techniques, a set of mathematical models meeting all these requirements could not be implemented. But by sacrificing just one condition--the discreteness of projects and the closely related nonlinearity of the dependence of expenditure on capacity--the other requirements become practicable within the framework of existing methods of linear and convex programming. In this way the following approach to modelling becomes possible.

Mathematical models of two types should be created for each branch (sectoral) system at the territorial levels of the hierarchy. Models of the first type will be used in choosing the basic optimum development trends for the branch system in harmony with other sectors, and in elaborating its basic internal structure and principal territorial links. Obviously, the discreteness and the resulting nonlinearity of the individual energy units are not vital in solving problems of this kind, and consequently they may be accounted for in an approximate way. The branch models of such type, together with a simplified model of the ESS as a whole, form the complex of models for optimizing the general energy system of the country (see Figure 3).

Models of the second type (see lowest left square of Figure 3) can be used to tackle more subtle problems in optimizing the development of each of the several branch systems (choice of equipment type and size, plant unit capacity, specialization and operation regimes, the necessary reliability of power supply, etc.). For these models, discreteness and nonlinearity are essential. For input these models use the solutions of the first complex of models, which take into consideration system interactions and unreliability of the initial data.

In this review we discuss mainly models of the first type. They are the most important for ESS development planning. Other energy models are too numerous to be mentioned in one review.

	Country	Economic Region	Industrial Center	Plant
General (aggregate) energy systems	Complex of models for optimization of the general energy system of the country	Models for optimization of regional general energy systems	Models for optimization of energy supply systems of industrial centers	-
Branch energy systems	Models for optimization of the country's systems: - electric power - gas supply - oil supply - coal industry - nuclear industry	Models for optimization of branch regional energy systems	Models for optimization of systems of industrial centers: - electric power supply - heat supply - fuel supply	Models for optimization of equipment and technological schemes of individual plants

Figure 3. Classification of energy models. (The model aspects considered in this paper are those to the left of the heavy line.)

MATHEMATICAL MODELS FOR ESS OPTIMIZATION

The elaboration of models is an involved creative process jointly performed by power engineers, economists, mathematicians and computer specialists. With progress in methods of mathematical programming and enhanced computer capacities, more is understood about the connections and properties of the system, and these are ever more adequately described in the model. The new improved models are usually based on studies of previous models and incorporate many of their elements. Therefore, if we wish to obtain a comprehensive picture of energy modelling, we must consider it in historical perspective.

The USSR's first mathematical model of energy economy (balance) was proposed in 1959-1960 by the Institute of Electronic Control Machines of the USSR Academy of Sciences [5,6]. In essence, it was built as for the transportation problem of linear programming and optimized the regional production and distribution of fuel on the assumption of completely interchangeable fuels and without distinction between the economic and energy effects of fuel utilization by consumers. This shortcoming was eliminated in the model developed in 1962 by the Siberian Power Institute (SPI) of the Siberian Department of the USSR Academy of Sciences [3,7]. The model gave a fuller description of the nation's economy (it optimized the production of all fuels except oil and light oil products, and their distribution over typical categories of consumer power plants). Yet it was only slightly inferior to the transportation model in its computational capacity, since it was confined to the distribution problem of linear programming. Extensive and prolonged efforts were made to work out various modifications of the distribution model in order to account for the multistage process of fuel extraction, processing and utilization, for some features of fuel processing, gas consumption regimes, capacities of existing plants, etc.

Those efforts laid the foundations for an improved production and distribution model, developed in 1967 by the Krzhizhanovsky Energy Institute and the Chief Computing Centre of Gosplan USSR. Along with other models, it was included in the *Methodical Guidance Instruction on ESS Optimization* [8] and is now being used in calculating the country's prospective energy balance.

The structure of the distribution problem of linear programming means, however, that models of this type cannot describe the entire complex of branch energy systems (and, among others, the oil industry). Moreover, it does not allow full account to be taken of such major energy factors as fuel processing, or the nonpermanent annual and daily regimes of electricity and fuel consumption. For this reason too, the distribution model cannot cover some of the important national economy constraints (e.g. limited capital investment and material and labor resources), nor can it give a full description of the dynamics of development of power industries.

In view of this, more complete models of the ESS based on the general problem of linear programming have been worked out, alongside the improved distribution models [9,10]. In principle, these models have made it possible to describe (in a linear form) practically all the elements and connections of the ESS and the dynamics of its development. However, this possibility could not have been put into effect because of the model's large dimensions (tens of thousands of equations and hundreds of thousands of variables). Nor has this basic shortcoming of such a model of the ESS been overcome in its simplified versions [11,12]. So the approach to its further elaboration has been to build a complex of mathematical models of the individual branches of the ESS and developing methods for coordination of the solutions to obtain a global optimum.

The first such models were developed in 1964-65 [13]. By considerable aggregation, the technological and territorial ties have been identified and studied from a practical point of view by the method of block programming. An instance of this block approach is given by the complex of mathematical models for optimizing the national energy system, developed at SPI [14]. It comprises four sectoral models (electricity and gas supplies and oil and coal industries), as well as models of the energy-consuming subsystems in each region studied.

Models for optimization of the general energy systems of regions and sectors have been and are still being developed in parallel with those for the national system. The state of Soviet research on mathematical modelling of the main energy systems can, in a sense, be characterized by the number of publications describing various models. By 1971, they numbered more than 140, with the following distribution over types of model:*

	Level of optimization		
	National	Regional	Industrial
General energy system	24	13	3
Electric power system	21	9	4
Gas supply system	14	13	4
Oil industry	14	7	3
Coal industry	8	5	

Analysis shows that, in the USSR, energy modelling has proceeded from overall comprehensive models to more detailed and specific tools for an optimal solution of less general problems. The other side of this approach is the necessity of typing the partial models into an integrated computing mechanism; in other words, building a coordinated set of mathematical models for energy systems optimization.

DESCRIPTION OF MODELS FOR OPTIMIZING ESS DEVELOPMENT

The models for optimizing national and regional energy systems and specialized models for the energy industries shown in Figure 3 are intended for five-year and long-range (10 to 15 years) planning, since directive documents are drawn up for five-year planning and the 15-year period allows for a wide range of possible changes in ESS structure. The models describe the fuel production, fuel processing, power production, and consumption units engaged in the processes of production, distribution (transportation) and consumption of various kinds of fuel and power; they also describe the connections resulting from the interchangeability of the energy carriers and a wide exchange of energy resources.

For each time range, the core of the model system is the general energy model of the country, referred to as the ESS Model. It describes, in aggregate form, all the components of the complex; its purpose is to optimize the proportions of complex development in harmony with the capacities and needs of other sectors of the economy, and to produce coordinated control information for independent optimization of the individual energy industries and regions. The general model examines and optimizes the scale of production and processing of various fuels; the development levels of fuel bases; the capacities and siting of new electric power plants of all types; the directions and volumes of interregional flows of fuel and electricity; the list of energy carriers for principal consumers; and the choice of the best pattern (in energy terms) of the location of the energy-consuming industries. As we have said, this model is in fact the complex of models which includes the simplified (aggregate) model of the whole energy sector and the first-type energy branch models of the country.

*For a detailed bibliography of Soviet studies in mathematical modelling of the main power systems up to 1971, see [15].

The national branch models of the second type (for the oil, gas and coal industries and electric and nuclear power), covering five and 15 years, are used in the investigation and optimization of the development of operational units and constructión of new ones (their capacities, processes, and operation regimes); the development of individual deposits; the priorities for putting new units into operation, and the upper limits for fuel production and electricity and heat output by particular energy systems; methods and volumes of fuel processing and concentration; choice of vehicles and schemes for specialized transportation of fuel and electricity; the introduction of new machinery, modern processes, and so forth.

Compared with the general energy model, a branch model gives a more detailed description of the development conditions for its sector, considers the particular plants and sites of the deposits and the special transportations routes, and specifies all the costs involved. In this way the resulting optimum decisions are made sufficiently specific to meet the needs of management in each industry.

Regional general energy models are designed to study and optimize the territorial output and consumption of local fuels and secondary power resources, intraregional links, schemes for supplying electricity to towns and farm consumers, allocation of energy carriers among consumer groups, and consumption schedules.

Compared with the national model, these models differentiate consumption centers, break down consumer groups into enterprises, specify the costs of transportation within the region, and give more details of the conditions and features of the region's ESS.

For tying in the national energy model with the branch models on the basis of optimization on a national scale the branch models are provided with the following data: (a) levels of development of the fuel bases within admissible intervals, allowing for errors in the input data; (b) capacities of various types of electric power stations, their allocations and fuels; and (c) consumption of particular fuels in the regions and interregional fuel flows. From the results of branch optimization, refined power engineering indices and the expenditures for fuel production and processing are entered into the national general model, as are the outputs (process volumes) of fuel at the individual enterprises in each sector, and the economic characteristics of the typical groups of electric power plants.

For tying in the national and the regional general energy models on the basis of regional optimization, the regional models are provided with the following data: (a) the amount of fuel from various deposits and basins of interregional importance, and the amount of electricity from intersystem electric transmission lines supplied to each region within admissible limits, with due account taken of input data errors; and (b) the marginal values of fuel and electricity in individual regions. On the basis of optimization of the regions, precise data are entered into the national model about the expenditure for intraregional distribution transportation, the composition of the aggregate consumption centers, and the groups of consumers with similar per-unit indicators.

Optimization in the model system considered is an iterative process. The methods of tying in serve to find the global optimum for the ESS as a whole. Analysis of computation alternatives leads to economically stable solutions for a number of alternatives, i.e. a set of alternatives equal in the economic sense.

Alongside optimization of the branch and regional energy systems, the planners have to solve a large group of relatively specific energy problems, deciding on such matters as the choice of energy carriers for smaller installations, the optimum parameters of plants and equipment, the optimization of energy production and consumption processes, and so forth. For solving these problems, a set of economic indices has been worked out and officially established in the USSR--the marginal values of fuel, electricity, and heat. The figures of these indices are determined from the dual solution (shadow prices) of the national general energy model [16].

Practically all the types of models described have been developed and are now being used in the USSR. The main task is still of organizing the smooth interaction of the models in planning, providing them with compatible and reliable input data, and eventually building up an automated system of plan calculations for the ESS.

MAIN INPUT DATA FOR OPTIMIZING ESS DEVELOPMENT

General energy models, both national and regional, and specialized models of fuel and power industries need largely the same categories of input data, though of widely varying specificity. Where the prices for all products are stable and government-controlled, of decisive importance in optimizing the ESS are the data on economy's demand for various kinds of energy carriers and on the ability of other (non-energy) sectors to provide the planned rates and proportions in developing the complex and its component industries.

Obtaining Information on Energy Carrier Demand

At present, the need for energy carriers is estimated in two different ways. One is extrapolation of current growth trends and proportions between the consumption of energy carriers and the macroeconomic indicators, i.e. the national income (gross national product), gross (net) industrial output, or the physical (in kind) growth characteristics of the key sectors of industry, etc. The changes in areas of energy carrier application are taken into account indirectly, using the elasticity functions characterizing the interchangeability of the various kinds of energy and fuel according to their costs.

The other approach, based on the merits of a planned economy, estimates the needs for energy carriers not by extrapolating the past, but by using the available plans for future development of economic sectors and by thoroughly analyzing the production processes to form the typical norms of energy consumption. With this approach, determination of the demand for fuel and power is no longer just a forecast in the narrow sense of the word, but a coherent system of computations (optimizing and informal analysis) reflecting the external relations of the ESS with all the other energy-consuming sectors.

Three factors determine the range of application of either approach to the estimation of fuel and power needs: (a) the rate at which structural and engineering innovations enter the sphere of material production; (b) the availability of reliable and sufficiently detailed information on energy consumers; and (c) the required accuracy of consumption estimates.

Taking account of the strengths and weaknesses of the two approaches to estimating energy demand in the Soviet Union, a method that combines both has been developed. Its core is the second approach, which serves to estimate the main part of energy demand; the remaining ("unnormed") energy consumption is projected by extrapolation.

The big difficulty with this method was to estimate the right proportion of computation and extrapolation. In substantial terms, this necessitates selection of a group of sectors and products whose energy needs must be estimated according to the consumption norms of energy carriers, i.e. by multiplying the planned outputs by the respective norms. This selection is usually made by listing the most energy-intensive products (or the most representative products involving a long and specific chain of intermediate products). Here a compromise is being sought between minimizing the list of products and covering the biggest possible share of the economy's energy demand on the basis of this list. Of course, in doing this, one widely known observation must be taken into consideration: if products are listed in order of increasing energy intensity, the longer the list the less the increment of "normed" energy consumption. This means that the effort of gathering and processing additional information available as a result of extending the list of products gives energy demand with decreasing precision.

From many years' experience in calculating the energy consumption for various sets of selected sectors and products, a list has been compiled that appears to be highly effective. Meanwhile, two questions had to be resolved: (a) measuring the physical outputs in sectors with an extensive and diverse product mix, and (b) establishing how representative are the energy carriers' consumption norms. These were no simple matters. Finally, a sufficiently satisfactory method was evolved for estimating the demand for energy carriers. As seen from Table 1, it can be used to compute up to 80% of the demand for electricity and heat and about 90% of the demand for fuel. Essentially, the method permits the following to be done.

For estimating industrial demand for electricity, approximately 40 products are considered in kind (Table 1); from these the electricity consumption in the light and the food industries is assessed according to gross outputs, and that in the machine-building industries according to the power needed for machine-tool operating and the heat required for thermal treatment (including smelting and heating) of all kinds of metal products. For the industry as a whole, the norm-based computation gives up to 70% of the total electricity consumption.

For other economy sectors (transportation, public utilities and services, and farming), electricity needs are estimated for numbers of applications and processes indicated in Table 1; this practically excludes any considerable unnormed electricity consumption.

For computing industrial demand for heat, 27 products (Table 1) are considered; they consume up to 65% of the total industrial heat. Heat for heating and ventilation in housing and public utilities is calculated on the basis of the population's housing standards, the heat-engineering characteristics of buildings, and the temperature in various regions. Heat expended on the hot water supply is assessed according to the projected requirements for this kind of utility.

The demand for fuel used by consumers directly is determined from its several uses: in industrial furnaces and technological installations; in small heating units serving the needs of housing, public utilities, farms, and other sectors; in mobile and stationary power units; and as raw materials. Generally, direct use of fuels in industries and services is of narrower scope than that of other energy carriers, especially electricity. The demand for fuels is thus easier to estimate and the normed share of energy demand becomes greater. For example, in industry, 32 products account for up to 85% of the fuel consumed in furnaces and other technological installations. For other specific uses, the rated share is even higher. On the whole, in the estimation of fuel consumption in the Soviet economy the normed share is about 90%.

Therefore, with this set of products and services, the computation method can give quite a large share of the overall demand for energy carriers. Since there are also norms for determining the total fuel expended on electricity, steam and hot water, the total share of the normed part in the overall demand for energy resources can be up to 85%.

Selecting a representative list of indicators of the development of the various economic sectors is just one way of enhancing the accuracy of the computation method. Another is the correct prediction of the consumption norms of energy carriers. Since the kind of energy carrier and its consumption norms depend directly on the kind of industrial process for manufacturing a given product, it is essential to take into account the influence exercised by the unit equipment capacity, the quality of the raw materials, the climate in the region, and other factors.

Table 1. Products covered and their share in total consumption of energy carriers.

Economy Sector	Electricity		Steam and hot water		Fuel	
	Number of products and services	Normed consumption (%)	Number of products and services	Rated consumption (%)	Number of products and services	Normed consumption (%)
Industry (whole)	41	66-70	27	50-65	32	85
Fuel industries	3	95	3	80	1	99
Ferrous metals	10	70	6	42	10	99
Nonferrous metals	8	80	4	33	7	90
Chemistry	10	55	8	55	4	95
Paper and pulp	4	40	3	45	-	-
Building materials	2	60	1	55	4	90
Machine building	2	80	-	-	1	95
Light industry	1	100	1	100	-	-
Food Industry	1	100	1	100	5	75
Transportation	4	88	-	-	4	95
Domestic sector and services	7	100	7	100	4	100
Farming	11	100	11	100	5	90
Total for economy	63	75-80	45	68-78	45	90

Usually, the choice of the kind of fuel or power for a consumer involves a comparison of alternative schemes of energy supply and optimization of energy supply sources with systems for energy transport and distribution. Existing strong feedbacks are extremely important for these interlinked calculations. Basically, this means that in making calculations to compare the competitive energy carriers one must know the costs of extraction (production) and distribution of all kinds of fuel and power; however, the costs themselves depend strongly on the integrated results of the choice of energy carriers. This controversy is resolved by using special indicators--the marginal values (of expenditure) of fuel and power--in selecting energy carriers, optimizing energy supply schemes, and solving other specific energy problems. The marginal values of fuel and electricity are a set of interlocked unit economic indicators characterizing the increase of the total expenditure in the national economy for the additional demand for these kinds of fuel and power in different regions. Marginal values are formed with regard to different mining and geological conditions, location, and quality of fuel (for more detail, see [16]).

From the use of marginal values, one obtains volumes of consumption of individual energy carriers that are optimal for the specific technology pattern and sufficiently harmonized with the future development of the entire ESS.

External Production Relationships of the ESS

Through its material production relationships, the ESS influences the development of many other production sectors whose products and services it consumes. If related branches of the economy are not sufficiently developed, they can considerably affect the production rate of efficient energy resources. It is therefore essential to examine the complex's external relations and take them into account in optimization.

The ESS production relations with some sectors are not only direct but also indirect, through other sectors; for example, its relations with metallurgical engineering are realized through the consumption of pipes and rolling stock. These relations intertwine with other external relations and largely depend on the specific conditions of developing the complex and the whole economy. For a quantitative evaluation of these relations, a special multisectoral dynamic model has been developed in the Soviet Union. It covers, in explicit form, the construction lags and distribution of material expenditure during the construction years [17]. For a given ESS development alternative, the model approximates the following requirements for implementation of the alternative: (a) volume of various industrial products, amount of construction work, and transport turnover (considering indirect as well as direct relations); (b) required capacities being commissioned in related branches with dates and priorities of this commissioning; and (c) the demands of related branches for extra capital and labor. This extra investment and labor must be added to the direct expenditure on ESS development; they are an additional objective when the final choice for ESS development alternatives is made.

Quantification of the complex's external relations takes into consideration only those economic sectors and industries that strongly react to the energy production pattern and growth rate and consume a large amount of the economy's resources. What is sought is not a plan for the development of the related branches, but just their response (extra output and commissioned capacities) to a given change in the production and consumption dynamics of a specific kind of fuel or energy.

Such a statement enables external relations to be estimated even when no detailed plan for the development of the related branches is known. But since only a part of their production is considered, constraints on the existing capacities cannot be incorporated in the model, because the proportion of these capacities serving to develop energy production through direct and indirect relations is not known in advance. Without such constraints it is impossible to see immediately from the model's solution whether or not the given alternative can be implemented. Additional analysis outside the framework of the model would be necessary for this.

A study of the intersectoral balance model [17] has identified the following set of industries and products which depend considerably on the optimization results for the ESS.

Economy Sector		Number of Products
Industry as a whole		56
Ferrous metals	10	
Nonferrous metals	6	
Building materials	6	
Power machines	5	
Machines for fuel industries	8	
Electrical engineering	5	
Machines for metallurgy	5	
Other machine-building industries	11	
Construction		2
Transportation		2
Total		60

Final decisions made for the ESS on the basis of optimization results must be tested for feasibility of developing the above economic sectors. Moreover, explicit constraints on the consumption limits of some 10 to 15 products must be included in ESS optimization. The list of these products varies according to the state of the economy.

OUTLINE OF INDIVIDUAL MODELS

Part II of this review consists of a tabular description of several of the mathematical models used in the USSR for research and long-range planning. Models of the lower levels of the hierarchy (see Figure 3) are not considered. We have selected those models of the three highest levels which are at most five to six years old, are described in publications, seem to be the best of their kind, and have been put to practical use on a fairly large scale.

Apart from the models for the ESS and for the country's branch systems, the review includes the model of the external production ties of ESS, used to account roughly for the influence of various ESS development alternatives on related branches of industry, construction and transport.

All models are described in the standard format of earlier IIASA surveys.

PART II

MODELS

The Model	A.A. Makarov, A.D. Krivorutsky, et al. 1975 [18]. Collaborating institutions: Siberian Power Institute of the Siberian Division of the USSR Academy of Sciences, Energoset'proekt Institute, All-Union Institute for Oil Industry Research, Central Research Institute of the Coal Industry, Institute of High Temperatures of the USSR Academy of Sciences, and the Main Computing Centre of the USSR State Planning Committee. Model of the general energy supply system (ESS).
Subject and Goal	The model is designed for multivariant optimizing calculations for investigating the range of possible conditions of ESS development and thereby finding a set of stable solutions, factors affecting unstable solutions, and a preferable alternative for ESS development; Coordination of development plans for the energy industries with one another and with the national economic balance, seeking a balanced alternative that would meet the given limits of capital, material, and labor resources.
System Described	The model is of block structure. It comprises three fuel blocks; (oil-producing and -processing, gas, and coal industries), the electricity block, and, for each region, a block of energy supply to consumers. The blocks are interlinked by the matrix of specific costs of energy for production of energy carriers and products, by the constraints on limited resources (capital, matèrial and labor), and by the general objective function (minimum discounted cost for the complex as a whole). By this method, each block can be formed, entered into a computer, and revised, independently. An optimum solution, however, can be obtained only for the model as a whole. The equations and inequalities in the model describe: the main technological processes transforming the energy resources from extraction to consumption (with allowance for all the process ramifications, feedbacks, and constraints); and the territorial ties of the ESS. The model thus ensures a balance of production and consumption of each kind of energy for particular regions as well as for the nation.
Area — Time	5 to 15 years. Optimization can be made either static (up to the end of the period) or dynamic (for separate periods within the time considered).
Area — Space	The country as a whole, with 25 regions selected for long-range planning, and 40 to 42 regions for five-year planning.
Modelling Techniques	The model is adapted for the general problem of linear programming. A special method for tying in and coordinating the solutions obtained for individual years (stages) has been developed for dynamic optimization of the ESS.
Input Data	<u>Physical</u> -Electricity demand and annual schedule of electricity loads in terms of duration; -Supply of heat from boiler houses and central-heating/power plants; -Demand for final energy (or product output) for consumers who can use various fuels; -Obligatory (nonsubstitutable) demand for each fuel, including export; -Rates of fuel expended on electricity and heat production; -Constraints on the production of particular fuels, hydro-electric power station capacities, product yields for various fuel-processing methods, throughput capacity of interregional links of the specialized transport network, etc;

	<u>Economic</u> -Unit costs and unit capital investment in extraction, processing, transportation and utilization of various kinds of fuel and power; -Potential limitations on capital, labor and material resources.
Problems by Block (Submodel)	<u>Oil and Oil-refining industry block</u> -Estimating reasonable volumes of oil production for oil-processing districts and big deposits; -Optimizing volumes and directions of interregional oil flows, taking due account of the throughputs of units of the existing pipeline network; -Estimating reasonable volumes and methods of oil processing in each region, and elucidating a reasonable pattern of oil-product production at existing and future oil-processing plants; -Specifying each region's demand for oil products, estimating their optimum outputs for individual regions and oil-processing plants, and determining the efficient transportation of oil products between regions. <u>Gas industry block</u> -Estimating reasonable volumes of gas production for regions and deposits; -Assessing reasonable rates of processing casing-head and special quality natural gas in particular regions; -Determining optimum volumes and directions of gas flows between the modes of gas pipeline networks (separately for existing and future lines); -Approximate estimation of efficient gas storage capacity; -Estimating optimum gas consumption for each region, taking into account possible regulating consumers. <u>Coal, peat and shale industries block</u> -Estimating optimum outputs of coal, peat and shale at basins and major deposits, separately for coking and power coals; -Determining reasonable amounts of coal to be processed by different methods; for coking coals, regions are to be specified where new concentration plants are to be located; -Optimizing the demand for various solid fuels in regions and, accordingly, the volumes and directions of interregional transportation of coals and their processing products. <u>Electricity block</u> -Choice of the best combination of capacities of various electric power stations with a view to elucidating the composition of new equipment and its required capacities; -Determining the capacities and sites for various power stations, and choosing fuels for existing and future thermal power stations; -Examining the need for building large interregional power transmission lines. <u>Fuel and power supplies block</u> -Determining reasonable expenditure of energy carriers in technological processes and for some public utilities; -Choice of optimal fuel for existing and new boiler houses; -Estimating reasonable volumes of consumption of each fuel by region, and specifying the regulating consumers; -In the first approximation, choosing regions for location of new energy-intensive industries. In addition to these problems, each block of the model estimates the capital, labor and limited materials needed by the sector concerned. Optimization calculations using this model enable a set of marginal values of fuel and electricity to be determined.
Observations	The model, with 1,500 equations and 16,000 variables, has been used by the USSR State Planning Committee in planning the development of the energy supply system to 1980.

The Model	Yu.D. Kononov, V.Z. Tkachenko, 1972 [19,20]. Siberian Power Institute, Irkutsk. Model of the external production relations of the energy supply system.
Subject and Goal	-Relations of the energy system with metallurgy, engineering, construction industry, transport, and other sectors directly or indirectly contributing to its development by their products; -Approximate estimation of the influence of a changed pattern and development rate of energy production, and of changes in the technology of production or transportation of particular energy resources, on the development of related branches and on the national economy's total expenses (in terms of investment, labor and materials).
System Described	The model covers all the main fuel deposits, groups of electric power stations and energy-production methods, and those industrial, transportation and construction sectors which largely depend for their progress on the development alternatives of energy production. The model takes into account that this dependence is complex and nonlinear and that some related branches have to be developed in advance of energy production. Extra demand for particular industrial products is assumed to be met either from expanded production capacities or from increased imports.
Area: Time	15 to 20 years ahead, described dynamically (in separate periods over the years considered).
Area: Space	The country as a whole.
Modelling Techniques	The model belongs to the dynamic input-output models, explicitly accounting for lags between the start of investment and putting into operation of production capacities. It consists of linear and nonlinear equations, describing for each year of the period concerned: balances of the production of individual products and services and their consumption in operating and building the energy systems and related branches; and the conditions for introducing extra capacities in related branches. An iterative algorithm is used to resolve the model.
Input Data	-Outputs of particular energy resources and commissioning of capacities in the energy system, specified by year; methods and ranges of energy transportation; -Import of individual industrial products for power production development; -Export of individual industrial products compensating for hard-currency outlays for imported power resources; -Coefficients (rates) of material expenses for operation and construction in the energy system and related branches; -Standard time rates for building and putting into operation of individual production units; -Capital investment per unit of capacity increment in all the industries covered by the model; -Allocation of investment by year of building; -Labor-intensiveness of particular products and building projects.
Output Data	Requisites for implementing the given development alternative of the energy system: -Outputs (direct and indirect expenses) of various industrial products, construction and transportation services; -Commissioning of capacities in related branches; -Priority of development of individual branches; -Direct and indirect (related) investment and manpower.
Observations	The model serves as a tool to study the effects produced by major and prolonged changes in ESS development on other economic branches (it consists of some 50 sectors and industries). It is also of help in long-range planning and forecasting for estimating the constraints imposed on ESS development by related branches; investigating the uncertainty zone of this development; and tentatively assessing the set of measures and the dates for implementing particular energy alternatives.

The Model	A.S. Makarova, A.N. Zeiliger, et al., 1971 [21]. Siberian Power Institute, Irkutsk. Model for optimization of the integrated national electric power system (INEPS).
Subject and Goal	The model is designed to find the overall strategy for developing INEPS; this involves the choice of an effective composition of generating capacities of different kinds for each joint (regional) electric power system (JEPS) included in INEPS and intersystems flow of electricity between JEPS's. The kinds of capacity are characterized by fuel used and by electric power station regime (peak load, manoeuver, basic).
System Described	The model core consists of equations and inequalities formulating the capacity and power balances for all regime zones of each JEPS. The following technical and economic constraints are taken into account: -Limits on the installed capacity and annual output of existing (and some future) stations; -Limits on the carrying capacity of main inter- and intra-system (between systems of particular JEPS) transmission lines; -Limits on the total capacity reserve in each JEPS, etc. The second group of equations specifies the balance of the limited energy resources. They include the possibility of using various fuels and changing the fuel used by existing stations. The third group describes the conditions for supplying INEPS with the material and labor resources needed (investment, various kinds of equipment, nonferrous metals, etc.).
Area: Time	5 or 10 to 15 years. Optimizations can be made either static (up to the end of the period) or dynamic (for separate periods within the time considered).
Area: Space	An integrated national electric power system is considered in which 11 JEPS's and 25 power systems are selected for long-range planning.
Modelling Techniques	The model is adapted for the general problem of linear programming. This is achieved by techniques reducing nonlinear relationships to a linear form. An effective algorithm of step-wise optimization has been developed; it solves the dynamic problem by consecutively optimizing and coordinating a set of static models, each describing the system state at some time step.
Input Data	<u>Physical</u> <u>Information on the annual demand for electricity (for the last year of each time step)</u>. -Electricity demand of each power system and each JEPS; -Combined maximum load of working days in winter; -Total required reserve capacity of each JEPS; -JEPS load duration curves, and their division among characteristic zones. <u>Technical information on electric power stations and transmission lines:</u> -Capacity of operational and some groups of new stations; -Contribution of stations to JEPS minimum zone of load duration curve; -Minimum and maximum possible values of hours of annual use, determined previously from the economic and technical features for each group of stations; -Carrying capacity of intersystem transmission lines usable during winter maximum and minimum loads for flows between JEPS'S; -Capacity loss factor of transmission lines; <u>Economic</u> -Per-unit investment in new stations and transmission lines; -Constant part of operating costs (depreciation, wages, etc.) for stations and transmission lines; -Per-unit expenditure of limited resources (equipment, nonferrous metals, etc.)
Output Data	-Optimal location and rate of use of particular types of power station; -Total capacity of each type of new station; -Types of fuel and its consumption volumes for operational and new stations and, in the first approximation, choice of their operation regimes; -Regions for optimum use of the electricity produced in the Eastern part of the USSR; -Rational volumes of intersystem electricity flows between JEPS's; -Total discounted expenditure for INEPS development during the projected period; -Marginal values for electricity, differentiated for JEPS's and for load schedule zones.
Observations	Several modifications of the linear dynamic model for optimizing INEPS' generating capacities have been successfully used, for ten years, in designing and planning, and also for multivariant studies of the roles of various factors (external relationships, electricity consumption regimes, development dynamics, etc.) for optimum long-range development of INEPS.

The Model	L.S. Belyaev, V.A. Khanaev, et al., 1974 [22,23]. Siberian Power Institute, Irkutsk. Optimization model of integrated electric power system.
Subject and Goal	The nation's integrated electric power system (NIEPS) or part of it is modelled for optimizing the development of its generating capacity pattern for various types of electric stations and equipment, at the same time choosing the carrying capacities of intersystem transmission lines.
System Described	The model core is made up of balances of capacity round the clock (for typical weekdays of each season), simultaneously (in common calendar time) for all the NIEPS systems. With these, the introduction time, emergency and repair, reserves, the plant's own energy needs, and capacity loss in transmission lines are taken into account. The model also includes the following constraints for each type of station and equipment: -On minimum and maximum new capacity to be commissioned (for hydroelectric power stations--on the building stages); -On operation regimes (technical minimum of plant units and stations, possible shutdown within 24-hours and on holidays, start and stop fuel costs and loading velocity, etc.); -On the specific features of types of station. The carrying capacity of transmissions is chosen to take into account the effect obtained from linkage of systems (different timing of peak loads, lowering of emergency reserves when systems are integrating, extra transport of electricity, etc.) and the distribution of the reserve capacity among systems.
Area — Time	5 to 15 or 20 years. The model can be made either static (up to the end of the period) or dynamic (for separate years within the period considered). The number of separate intermediate years in the dynamic mode depends on available computer capacity. Up to 8 typical 24-hour periods may be considered in each year.
Area — Space	NIEPS or part thereof (several joint electric power systems (JEPS's) or one JEPS) is considered with up to 25 selected power systems (with corresponding transmission lines) and up to 250 groups of similar plant units in the whole NIEPS.
Modelling Techniques	The model is based on linear modelling principles. It minimizes the total discounted expenditure for development of the NIEPS. The auxiliary function method seeks an optimum solution; it makes possible the explicit inclusion of nonlinear dependencies, such as the capacity loss in transmission lines depending on the flow volume, the decreased need for an emergency reserve depending on the carrying capacities of links, the capacity of hydroelectric power stations depending on their output in low-water years, etc.
Input Data	-Annual electricity output and load schedules for typical 24-hour periods; -Constraints on capital investment, fuel supplies (specified by type), main electricity flows, and equipment supplies; -Initial pattern of generating capacities and intersystem transmission lines; -Unit prices and constant part of operating costs for individual types of equipment and transmission lines; -Technico-economic indicators for groups of similar plant units: minimum admissible load; admissible number of shut-downs overnight and on holidays; coefficients of emergency, of repairs, of own needs, etc.; -Minimum electrical load of combined heating and electrical plants for various parts of the days over the week and for seasons; -Daily (for different seasons) and annual average multiyear outputs by hydroelectric power stations; -Efficiency and capacity relationship of hydro-accumulating stations and maximum number of hours for operation in the turbine regime; -Dependence of capacity loss in intersystem transmission lines on the flow volume.
Output Data	The results of the calculation are differentiated for time levels (years), power systems, groups of similar plant units of stations and transmission lines, and typical days and seasons; they include: -Value of the objective (discounted expenditure) and (separately) capital investment and operation costs; -Characteristics of development (installed capacity) and of utilization (reserve capacity, electricity output, hourly loads for typical days, fuel costs and consumption, etc.) for power stations and transmission lines; and other information.
Observations	The model has been implemented in FORTRAN on the BESM-6 computer; the program-and-information complex consists of seven auxiliary and function subsystems: dispatcher, data bank, input, model, optimizer, output, and standard solutions. The complex is built on the modular principle. At the user's request, it automatically applies the model in several modifications differing in purpose and set of factors covered. The complex is designed to solve problems with 3,000 to 3,500 general equations, including about 15,000 variables.

The Model	A.M. Belostotsky, V.E. Zamergrad, M.V. Sapozhnikov, 1972 [24]. Institute of High Temperatures, USSR Academy of Sciences, Moscow. Model of nuclear power engineering in national energy systems.
Subject and Goal	The model of a subsystem of nuclear power engineering is designed to assess optimum levels and ways of developing nuclear power engineering, location of atomic power stations throughout the country, and impact of nuclear power engineering on other subsystems of the energy system.
System Described	The model represents nuclear power production as a set of atomic power stations of various types and of plants for extraction and concentration of natural uranium, manufacture of fuel elements, and processing of utilized fuel. A special block describes the conditions of mining and interregional transport of coal, gas and fuel oil. The block of the integrated electric power system takes into account the daily and annual operation schedules of operational and future power stations of different types and of intersystem transmission lines. Each vector in the model (except for those describing the units of the nuclear fuel industry) is a fixed alternative pattern of functioning of a unit from the start of its operation to the end of the projected period. For each power unit, several alternatives (vectors) for its functioning during that period are defined. A linear combination of the vectors, obtained from computing the model, characterizes the optimum functioning of the unit concerned. The units of the nuclear industry are described by vectors which enable them to be presented as active, in mothballs, or dismantled. Thus, the units can function in any mode, as required by the conditions for their optimum commissioning and use.
Area: Time	Perspective of 15 to 20 years, dynamically (separate periods within the time considered).
Area: Space	The country on a regional basis.
Modelling Techniques	The optimization model makes use of a linear programming algorithm. The function comprises the total discounted expenditure for the system.
Input Data	<u>Physical (technical)</u> -Energy demands; -Constraints on total capacity of nuclear reactors of certain types; -Capacity of power plants operational by the start of the period, and available conditions for the development of new units; -Technical indicators of various electric power stations; -Technical characteristics of the nuclear fuel industry; -Constraints on the capacities of the extraction industry. <u>Economic</u> -Expenditure for extracting, transporting, and processing fuel and power resources.
Output Data	<u>Physical (technical)</u> -Capacities of individual types of electric power stations, specified for the years of the period considered; -Demand for nuclear fuel, specified for years; -Capacities of individual enterprises in the nuclear extractive and processing industry. <u>Economic</u> -Marginal values of nuclear fuel; -Estimated efficiency of atomic power stations.
Observations	One shortcoming of the model is the "rigid" description of functioning of the units; an advantage is that a dynamic study of the properties of the units and of the system can be made.

The Model	D.M. Kazakevich, 1972 [25,26]. Institute of Economics and Industrial Management, Novosibirsk. Model of development and location of coking-coal production
Subject and Goal	The model of a system of supplying coking coal to the national economy is designed to choose optimum development alternatives for individual mines and pits and to set out a scheme for coal supplies in terms of coal grades and the charge for coking (in aggregated form) at coking-chemical plants.
System Described	Alternative patterns of development for mines and pits are characterized by the overall coal output and by outputs of individual coal grades. The alternatives differ, moreover, for new coal mines in the starting dates of construction and the duration of development, and for existing mines, in the degree of rebuilding and expansion. The coking-coal demands of individual plants and workshops are differentiated by the coal grade groups over an admissible variation range. For the conditions of the coking process, constraints are introduced on the total volatile-matter yield and the working layer thickness. The objective is to find an alternative that would involve minimum total (current and capital) expenditure during the period considered, for mining, concentration, and transport of coal. The expenditure for coking coal consumption is included in an indirect way, through the indicator of reference charge.
Time	Up to 15 years, the calculation period being two or three years longer (to allow normal conditions to be reached for the projects to be put into operation at the end of the planned period).
Area Space	The country as a whole.
Modelling Techniques	The model is stated as a multiproduct production-transportation problem with discrete variables. A method has been developed for its approximate solution.
Input Data	Technical -Alternative patterns for outputs and methods of mining a given coal grade at each mine (pit) specified for the years of the period; -Volatile-matter yield and the coking layer thickness for a given coal grade (specified by basin); -Coke output (in reference units) of each coking-chemical plant; -Limits on the content of various coal grades in the charge; -Transfer of coefficients from real coal and coke to reference coke. Economic -Integrated production expenditure for the planned period for each development alternative of a given plant; -Coal transportation expenditure.
Observations	The model has been used to optimize the long-range plan of development and location of coking-coal production to 1980 for 355 mines and pits and 45 coking-chemical plants. From 1 to 19 alternatives were examined for construction, rebuilding, and operation of coal plants.

The Model	A.S. Nekrasov, T.M. Polyanskaya, et al., 1972 [27]. Central Economic-Mathematical Institute of the USSR Academy of Sciences and Central Economic Research Institute of the Coal Industry, Moscow. Model of the coal industry.
Subject and Goal	Development and location of mining and processing of energy coals.
System Described	Taken into account are: the specific features of the coal industry (mining) and its links with the nation's fuel and power balance; technologically possible coal outputs of individual mining enterprises; the possibilities of reworking coals resistant to heat and to mechanical processing, and the grades of these coals; and the need for meeting the fuel demands of all user groups in all regions of the country. The demand for energy coals links the coal industry with the national energy balance.
Area — Time	Perspective of 10 to 15 years.
Area — Space	The country as a whole and individual aggregated regions.
Modelling Techniques	Linear programming. The objective function is the minimum total expenditure on mining, processing, transportation and utilization of energy coals. The nonlinear dependence of per-unit expenditure on mining output is taken into account by means of its separable representation.
Input Data	<u>Physical (technical)</u> -Technologically possible coal outputs; -Output coefficients for different coals; -Demand for energy coals by individual consumer groups, specified for various economic regions; -Substitutability factor of various coals for consumers. <u>Economic</u> -Per-unit expenditure for mining, processing, transporting, and burning coals.
Output Data	-Output of mined and processed coals at particular plants, and deposits; -Coal flow to consumers in individual regions of the country.
Observations	The model is used for the long-range planning of coal industry development to 1990. The model is being improved as regards the dynamics and directions of possible development variants for individual enterprises.

The Model	A.S. Nekrasov, A.I. Mekibel, D.F. Kasatkin, Yu.I. Chernyi, 1972 [27]. Central Economic-Mathematical Institute of the USSR Academy of Sciences and All-Union Research Institute of the Oil Industry, Moscow. Model of the oil-producing and oil-processing industry.
Subject and Goal	The model is designed to optimize development, location, and specialization of the oil-producing and oil-processing industry.
System Described	Optimum development implies satisfaction of the economy's demand for oil products at minimum discounted expenditure for producing, processing, and transporting oil and oil products. Six petroleum products are singled out: gasoline, kerosene, diesel fuel, raw material for petrochemistry, boiler and furnace fuel, and oil bitumen. Oils are not treated separately since it is assumed that the problem of optimum planning of their production has already been solved. The model includes various technological constraints as well as the usual balance equations characterizing production, processing and exchange of oil and oil products between regions. The constraints include, in particular, limits on the supply of certain crude grades to individual processing plants with fuel-and-oil schemes, limits on the extent of processing at these plants, etc. The demand for boiler fuel as a product interchangeable with other kinds of fuel and energy is a variable. The upper and lower limits on supplies of boiler fuel to each region are defined.
Area — Time	5 to 15 years ahead.
Area — Space	The country as a whole with selected economic regions.
Modelling Techniques	For model statement, production capacities of processing plants are approximated by a convex polyhedron. This method presupposes treating the capacity of a plant and its expansion in an integral form and implies introducing additional constraints on the amounts of crude oil involved in existing technological processes. The model corresponds to a linear programming problem.
Input Data	<u>Technical</u> -Upper limits on crude oil outputs for individual fields; -Capacity of existing oil-processing plants and their potential development; -Throughput capacity of existing pipelines for crude and for oil products; -Regional demand for petroleum products; -Maximum and minimum yields of oil products and their combinations in processing each of 12 groups of oils; -Technological constraints. <u>Economic</u> -Discounted expenditures (per unit) for producing, processing and transporting crude oil and oil products; -Marginal values of boiler fuel in consumption regions.
Output Data	-Crude oil output for individual oil-producing regions, and distribution of crude oil among processing plants; -Location of plants and their capacities; -Output of individual oil products at processing plants, and their distribution among consumer regions.
Observations	The model has been used for multivariant calculation in optimizing the development and location of the oil-producing and oil-processing industry of the USSR for 1975-1980. The total number of equations was 380; that of variables 2,700.

The Model	A.I. Mekibel, 1974 [28,29]. Central Economic-Mathematical Institute of the USSR Academy of Sciences, Moscow. Model of long-range planning of the oil-processing industry.
Subject and Goal	A two-level system of models is designed to optimize the development and location of oil processing, taking into account the discreteness of standard capacities of processes and plants.
System Described	Complexes of oil-processing plants and the interregional transportation of oil products are described in the framework of the industry as a whole; individual plants and the intraregional distribution of oil products are described at the regional level. The constraints characterize the conditions of production and distribution of crude oil of various kinds, the production and use of straight-run cracking fractions at the plants, and the production and transportation of petroleum products.
Area: Time	10 to 15 years. The development of oil processing is optimized in successive 5-year periods.
Area: Space	The country as a whole and individual regions.
Modelling Techniques	The upper-level model is formulated in terms of linear programming; that of the lower level makes use of both continuous and discrete variables. The objective function is the minimum total discounted expenditure for production and transportation of crude oil and the production and distribution of oil products. The development technique of aggregating the production capacities of the processing plants allows the model dimensions to be reduced with only slight aggregation error. The plant model includes treatment variants for straight-run cracking fractions, calculated with due regard to constraints on crude and product quality.
Input Data	<u>Physical</u> -Demand for oil products (14 kinds) by regions; -Crude output by regions; -Existing network of crude and product pipelines; -Existing processing plants; -Local constraints on process and plant capacities, product quality, etc. <u>Economic</u> -Discounted expenditure per unit for crude production and transport; -Discounted expenditure (per unit) for each variant of crude oil processing at plants.
Output Data	Distribution of crude among processing plants; location of new plants and expansion and rebuilding of existing ones; amount of crude processed in various processes and plants; output of oil products by plants and their distribution among consumers, with regard to transportation conditions.
Observations	Models of various levels have been used for tentative and practical calculations of long-range plans for the oil-processing industry. A scheme is now being elaborated for coordinated solutions in the system of models, with dynamic and stochastic factors taken into account.

The Model	E.P. Druzhinin, Yu.A. Kuznetsov, et al., 1970 [30]. Siberian Power Institute, Irkutsk. Model for optimizing the development of the integrated gas supply system.
Subject and Goal	The model represents the integrated gas supply system (IGSS) of the country or part of it (IGSS section), or a regional gas supply system (RGSS). Its purpose is to optimize the location and development of gas production, choose specific main and seasonal gas consumers specified as consumer groups, and optimize the layout of gas transportation flows and their development over time and the location pattern and use of underground gas holders. The model takes into account the current state of the system and its ties with the energy supply system.
System Described	The core of the model comprises (for each year or time interval) the capacity and load balances specified for the seasons (winter, summer, peak) at all IGSS modes, taking into account the rebuilding of existing units and the development of new units (including own demand of equipment). Besides the balances, the model accounts for: -An advance of capital and material investments for development of IGSS units; -Seasonal gas consumption regime and its possible compensation from gas deposits being worked out and from underground holders, from gas transport systems (including reversible gas flows), and by a more specific choice of gas consumers; -Constraints on the expenditure of material and technical resources and capital, both for individual years and for the whole period; -Constraints on the capacities and operation regimes of the existing IGSS units. When the throughput capacities of individual pipelines and the gas transport system as a whole are being chosen, equivalent characteristics of pipelines are used.
Area — Time	5 to 10 or 15 years ahead. With adjustments, the model can design the IGSS in the coming five years and decide some planning issues. It can be made static (to the end of the period) or dynamic (for separate periods within the time considered).
Area — Space	Integrated gas supply system of the country (either IGSS section or RGSS) with 50 to 70 modes chosen.
Modelling and Computing Techniques	The model is based on the principles of linear programming; it minimizes the total discounted expenditure for IGSS development over the period. Some linear dependencies and the discreteness of the development of IGSS units can be taken into account, using equivalent techniques elaborated for this purpose.
Input Data	-Equivalent scheme of IGSS, covering in sufficient detail the production, storage and consumption of gas, and adequately representing the existing and developing gas transport network; -Annual demand for gas and its consumption regime during the year by consumer group for each node of the IGSS equivalent scheme and each calculation year; -Constraints on possible gas output at each deposit for all the calculation years (for deposits actually in use with allowance for declining yield); -Constraints on the use of existing and new underground gas holders for all the calculation years; -Constraints on the throughput capacities of the existing gas transport network, potential schemes for network development (specified for the calculation years), gas expended on own needs, etc.; -Constraints on material and technical resources, and capital investment; -Technico-economic characteristics of production, transportation, storage and consumption of gas (by individual consumer group) for each calculation year, according to the equivalent scheme of IGSS accepted for the study.
Output Data	The results are differentiated over the calculation years of IGSS development and over the nodes of the IGSS equivalent scheme (i.e. by consumer group, gas deposit and underground gas holder). They cover the whole gas transport network and its units and take into account the regimes of production, transportation, storage, and consumption of gas during the year, and ways of compensating for seasonal fluctuations in gas consumption. They include the optimum development schemes of IGSS units and give the values of the objective function (discounted expenditures) and also (separately) of capital investment, the operating costs of IGSS proper, and the closing fuel for consumers with double fuel supplies (gas and closing fuel).
Observations	The model has been used in the study of optimum routes for the long-range development of the USSR IGSS (to 1990). The model dimension was 500 equations and 1,500 variables.

The Model	V.N. Khanaeva, A.A. Makarov, 1970 [31]. Siberian Power Institute, Irkutsk. Model of the regional general energy system.
Subject and Goal	The energy system comprises regional systems of the electricity and gas supply industry, the coal, oil, and oil-processing industry, and the energy systems of regional consumers. The model is designed to work out an optimum long-range fuel and power balance for the region and to elaborate the decisions taken on the sectoral and national levels of the hierarchy.
System Described	The model comprises the following interlinked blocks: -The energy economy blocks of industrial centers, which include equations of the balance of production and supply of heat by individual plants of the centers, using various fuels, or else the balances of production and supply of the main products of a large enterprise (when choosing an efficient scheme of energy supplies); -The electric power system block of the region, consisting of the capacity and power balances of each center with regard to the intersystem inflow. In the first approximation, the model takes into account the operation regimes of large electric power stations and transmission lines. This is achieved by considering several alternative operation models (quasi peak and basic loads); -The gas supply system block of the region, comprising equations of balance of production (extraction) and consumption of gas for summer and for winter; -The coal block, in which each center is assigned equations of the balances of production (mining) and consumption of coal, and constraints on coal production in all basins; -The oil-products block, which includes equations of the production and consumption by each center in the region, and constraints on the consumption maximum of local and imported oil products. The objective function of the model is the sum of the calculated costs of production, processing, and intraregional transportation of all fuel, the costs of electricity production, of distribution transportation, and of fuel used by various consumers in all industrial centers of the region.
Area: Time	Perspective of 10 to 15 years, broken up into two or three time intervals; calculation is made successively to the end of each interval.
Area: Space	Separate aggregated economic regions.
Modelling and Computing Techniques	The model is stated as a general problem of linear programming.
Input Data	-Annual demand for fuel or final energy by all the installations of the consumers in the region, specified by centers; -Costs of fuel utilization; -Costs of fuel production at deposits and basins within the region, and costs of main and distributive transportation; -Maximum technologically possible outputs of various fuels in the region's deposits and basins, and admissible amounts of consumption of imported fuel; -Marginal values (shadow prices) of imported fuel from various deposits and basins of interregional importance, and marginal values of electricity.
Output Data	-Specific evaluation of demand by the region's general energy system for fuel imported from various deposits and basins; determination of reasonable performance and ways of development of local fuel bases; -Determination of efficient intercenter flows of various imported and local fuels (including oil products) with regard to the efficient volume and location of intraregional fuel storage; -Specific evaluation of capacities, location, and electric and fuel regimes of the main electric power stations of the system; -Location of power-intensive production units; -Distribution of fuel and electricity over centers and, within each center, among consumers. -Specific estimation of the marginal values of fuel and power, taking distribution transportation into consideration.

The Model	A.S. Nekrasov, A.I. Stanevichus, 1970 [31]. Central Economic-Mathematical Institute of the USSR Academy of Sciences, Moscow. System of models for long-range planning of the development of the energy economy in a region.
Subject and Goal	The model is designed to work out the optimum structure of the fuel and power balance of an economic region.
System Described	The system comprises a regional model of fuel and power consumers and the models of regional sectoral systems: the oil, gas, coal, and electricity supply systems. The schemes for energy supplies to individual towns, major enterprises, and farm districts are represented in the regional model by their aggregated characteristics. The regional model is tied in with the sectoral models through common constraints on energy resources external to the region concerned. The relationship is also due to the fact that the enterprises concerned with the production, processing, or conversion of energy resources enter both the sectoral models (as fuel and power producers) and the regional model (as consumers).
Area: Time	Horizon of 10 to 15 years (end of period).
Area: Space	Individual economic regions.
Modelling Techniques	Coordination of optimum plans for the regional and sectoral models of a region's energy economy comes down to the solution of a linear programming problem of large dimension whose constraints matrix has a block structure. A modification of the decomposition algorithm is used, which consists basically in solving a succession of truncated problems. The optimum is assumed to be a solution minimizing total outlays on production, processing, transportation, and use of fuel and power. The energy resources imported from outside are estimated from the marginal values.
Input Data	Physical (technical) -Maximum possible volumes of production and processing of local fuels; -Possible inflows of energy resources from other regions; -Obligatory export of energy resources produced (mined) in the region; -Product outputs or energy demands by various consumer groups; -Possible schemes for development and parameters of oil and gas pipelines and electric power transmission lines. Economic -Marginal values of imported energy resources; -Costs of local fuel production and transport; -Energy-economic characteristics of fuel consumers.
Output Data	-Scale of production and processing of local fuels; -Consumption of all kinds of fuel and power by various consumer groups; -Efficient layout of intraregional fuel and power flows; -Specific description of the interregional distribution of power resources.

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