# LONG-TERM PLANNING METHODS FOR THE PRODUCTION AND ALLOCATION OF ENERGY*

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The special importance and efficiency of meeting demands for energy follows partly from the fact that the production of energy (as well as its transformation and import) are in the closest connection with the development of the producing and servicing branches of economy and with the consumption by the population, and partly from the fact that the investments serving the production and allocation of energy are expensive and their gestation period is rather long. Recently, the importance of importing energy has greatly increased, not only for developing countries where the prime sources of energy are scarce, but even for such countries which are rich in traditional sources of energy. Undoubtedly Hungary, too, will import an increasing part of sources of energy in the future. The importance of *long-term planning* in the sector of energy is determined by the fact that — among others because of the volume and long gestation period of investments — economic decisions on the main problems, thus on the volume and pattern of the sources of energy to be used, on the proportion between domestic production and import, as well as on the allocation of sources of energy to the main users must be taken well in advance.

We may consider the following as the main stages of long-term planning which, of course, are in close connection with one another:

1. The preparation of planning by a comprehensive survey and analysis of the technico-economic interrelations, main development tendencies of the area covered;

2. The forecasting, prognosis of the (expectable) development of the economic process or phenomenon in question;

3. The planning of the equilibrium (and of proportionateness); and, finally,

4. The planning of the most rational utilization of resources (the efficiency computations), as the concluding phase for planning and at the same time the basis for concrete economic decisions.

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In this paper we are to deal with the problems of the question mentioned last, with the computation of efficiency.

## The main tendencies in the production and utilization of energy

As is known, in the last decade important changes have taken place all over the world as regards the development of energy utilization. These can be briefly summed up in the following: In connection with the rapid economic growth also the rate of energy utilization has accelerated, e.g. from 1950 to 1958 the energy consumption of the world has increased by about 50 per cent, which is roughly the same as that in the preceding twenty years. Besides, this rapid growth was partly accompanied by a decrease in the specific utilization of energy, i.e. with the improvement of efficiency, in the transformation and utilization of energy alike. In addition, in the sector consuming most of the energy, namely in industry, the structure generally changed in such a way that the sectors having a smaller demand for energy grew faster, which again resulted in a decreased specific industrial energy consumption. The above process was aided by the most significant change in the structure of basic sources of energy used, the well-known advance of oil and natural gas against coal. These sources of energy can generally be utilized much more efficiently (and in most cases with smaller investments) than coal. This advance of hydrocarbon at the same time resulted in a very rapid growth in the share of import energy used in most of the industrial countries, especially in Western Europe, where it caused the stagnation and partly the decrease of coal mining and thus the Western European coal-crisis.

These phenomena and especially the fact that on basis of the development experienced and following from geological researches, a significant rise in the production of oil and natural gas might be reckoned with, this changing the rather pessimistic prognoses of the past as to the possible satisfaction of demands for energy. E.g. in the middle of the fifties in Western Europe it was calculated that in the next decade a general shortage of energy was to be feared, and as a consequence home production of coal should be increased even at the cost of great sacrifices. To-day as opposed to that it is assumed that the proportion of coal will rapidly diminish in the next years and by 1975 it would cover only 25 per cent of the total use of energy in the countries belonging to the European Economic Community. (Which naturally means that at the same time three quarters of the energy used will be of import origin.)

Up to the middle of the fifties, in Hungary too, a great part of specialists considered the perspectives of energy supply rather pessimistically; they did not reckon with the possibility of greatly increasing the use of oil and natural gas, they thought that meeting the increasing demands for energy could be ensured, besides large imports of coal, only through the building of atomic power stations. Since then they consider both the possibilities for home production of oil and natural gas and the long-term perspective of imports of oil in a more optimistic way.

## Long-term prognosis of demands for energy

In the methodology of establishing the long-term demands for energy we may distinguish three methods which, however, cannot be strictly separated from each other. The first method aims at establishing the expectable demand for energy purely *with the aid of extrapolation based on the development of the past period as a function of time.* The mathematical-technical tool of this method is the computation of trends. The basic assumption of extrapolation with the aid of trends is that in the future the same effects as in the past will prevail, i.e. by substituting a future period into the function approximately describing the past development of energy consumption, the magnitude of the demand for energy can approximately be established. — This method can be accepted in long-term planning only as a first and very rough approximation; its only advantage being that even without knowing other data of the expectable economic development it can serve as an initial hypothesis for establishing the approximative magnitude of the demand for energy.

The next method is based — as against the former one — *on the causal connection between the use of energy and its main factors.* With this method it is established what past connections had been between the use of energy and such economic parameters as are in close connection with the magnitude of the use of energy, e.g. between total energy consumption of the national economy and national income, or between the volume of industrial production and industrial use of energy. These long-term estimates — the technical tool of which is correlation computations — might be suitable for a somewhat more precise approximative estimation of the demand for energy in long-term planning when, knowing the main development rates and proportions, there are no detailed computations still available.

For a more detailed and reliable estimation of demands the so-called synthetic method serves. To apply this one in planning, the expectable development of the main consumer branches and of the specific use of energy must be known. To ascertain the latter, international data are needed for comparison and also the home targets of technological development must be known. Our present long-term planning of energy cannot from the point of view of the specific use of energy be considered as quite satisfactory and solid, as it is not based entirely upon reliable homogeneous specific energy consumption figures for products, but rather upon more uncertain methods of estimation. When, therefore, judging long-term computations of the demands for energy, the limits within which these plans — considering the exactitude of planning and other parameters serving for basis to the plans — can be looked upon as realistic and are also to be taken into account. The exactitude of the basic data — especially of the specific energy consumption figures — is also in connection with the detailedness of planning. The demand for energy for instance of a given homogeneous product can in general be planned more exactly than that of a branch containing heterogeneous groups of products.

## The long-term balances of energy

Planning the demands for energy relying on the plans of the consumers and on the specific number of energy consumption, already leads to the drawing up of the balances of energy. It is only natural that we cannot be satisfied either with a global estimate of needs only or with their more detailed planning and that for working out the long-term plan it is necessary to plan the *demands for and the sources of energy simultaneously* and *to coordinate these.* This coordination takes place through a more detailed long-term planning of the home production of energy and of imports of same, as well as through planning the demands for energy by their main groups and further by harmonizing all these sources of and demands for energy with the aid of the long-term balance of energy. The utilization of the long-term balance of energy for a more exact calculation of proportions corresponds with the general practice of planning. It is well known that the various balances play a central role in the planning of socialist countries. For shorter periods, the utilization of planned balances of energy has for long been a general practice and also in the long-term plans made till now, the method of balance has been employed more or less consistently and with more or less detail.

The specialists of energetics have agreed on the main problems of the methods of drawing up and working out the long-term plans of energy. At present it is debatable and debated in the first place only how detailed the balances should be, what system they should follow, and whether the system should be the same for different periods of planning. In this question decision must be made, on the one hand with regard to the *purpose* of planning, and on the other hand considering how exact and detailed are the basic data available. On broad lines, the considerations affecting the establishment of the system of long-term balances of energy might be the following:

In general it is unnecessary in the computations to employ an ever increasing number of branches, products or homogeneous consumers of energy. In establishing the demands only such a degree of detail should be aimed at, where all sectors (products), for whose production volume and specific consumption of energy there are more or less reliable data, should appear separately. More detailed than mentioned above do not render the planning of the demand for energy more precise.

Besides, depending on the period of planning, balances differing in detail can also be justified. In the perspective relating to which final economic decisions (e. g. decisions on investments) are needed, and in which the production figures and those of specific consumption can be considered as fairly reliable, efforts should be taken to have more detailed calculations. For a perspective, however, where the establishment of production and of specific figures becomes quite uncertain, it is sufficient to work out comprehensive, summarizing data.

Further points of view are offered for developing the system of the balance of energy by calculations as to the most rational use of resources (efficiency calculations) with which we will to deal in detail in the following.

## Efficiency calculations

For concluding the planning procedure — besides knowing the main development tendencies, the numerical prognosis of demands for energy and the long-term balances — *it is also necessary to plan the most rational utilization of resources*, i. e. the calculation of efficiency. As a rational, optimal utilization of resources can in a socialist planned economy in the last resort be interpreted only at a level of the whole of the national economy — considering all of its complicated interrelations — this calculation is extremely complicated. It is a little surprise, therefore, that it is here that the computation methods are the least developed.

As far as can be expected of the planning the most effective utilization of all resources of the economy — it is just this aspect of planning that it is the most essential part of the planning procedure. The prognosis, i. e. the establishment of the expectable development, or even the planning of the different proportions — thus the determination of the balance — cannot be identified with planning, or rather, planning cannot be considered as concluded when the previous computations are ready. In practice we often meet with a standpoint which is essentially a neglection of this third, most important phase of planning. As a matter of fact, even the previous stages of planning should be examined from this point of view, the application of the various possible methods should be judged by how far they support the most essential part of planning: the planning of the most rational (optimal) utilization of resources. The long-term plans (or computations) of energy in this country made up till now do not contain a detailed and scientifically well founded efficiency computation relating either to the planned proportions of sources of energy or to their allocation to the various categories of consumers. This is a major deficiency of the plans, both as regards methodology and their contents. Even the tendency of increasing the ratio of oil and natural gas and their planned distribution among various categories of consumers — though made on the basis of different technological and economic considerations — essentially prevailed without calculating efficiency based on scientifically sound methods. In spite of these deficiencies, the situation is now far better than it was even one or two years ago.

As regards the supply of energy, considerations of economy had as compared to their significance but little scope in Hungary in the past. The prevailing view — and not only in Hungary — considered the domestic mining of coal as the main base of energy and thought that its development was necessary as a matter of fact — even independent of economic calculations — arguing that the domestic demand for energy cannot be met in any other way, but by the rapid development of coal production. This conception which might be regarded rather autarchic from the point of view of energy supply, hardly presents itself to-day and a general effort is to be felt for establishing the right proportions of energy supply and utilization on the basis of efficiency calculations. The calculation of efficiency must, of course, be sound and scientifically justified. An efficiency calculation for instance, which compared the costs of coal imports with the *average* costs of domestic coal production, supported the autarchic concepts (obviously in case coal is imported, it is not the coal which is mined with average costs that can be economized but, at least in principle, the most expensive one). As a matter of fact, this autarchic concept bears some relationship to another kind of efficiency calculation trying to determine the optimal level of domestic coal production, exclusively on the strength of investigations into the costs of coal production, considering as optimum the level of production above which the specific costs of coal production are already very rapidly rising — thus neglecting the interrelations of the economy, e. g. the possibility of substitution among the sources of energy.

The efficiency calculations needed for laying the foundations of long-term plan of energy are — from the point of view of methodology — much more complicated than the usual ones. The methods for calculating the efficiency of investments and of foreign trade are fairly well developed. The method for calculating the efficiency of investments which is laid down in the instructions of the National Planning Office — and which is compulsorily applied at least with great investment projects — is more or less suitable when variants of investment projects serving the same production (servicing) purpose should be compared. If however investment projects for different purposes, e. g. those belonging to different branches of industry must be compared, the applicability of the method might already be contestable.

The methods developed for calculating the efficiency of foreign trade relate to the efficiency of exports. Here, too, satisfactory results can only be arrived at if it is a question of comparing various products that can be produced with existing production equipment. The methods for calculating the efficiency of imports are less developed.

With long-term planning of energy the task of efficiency calculations is far more complicated than those mentioned previously. Here the costs and results of investments into different branches must be compared at the level of the economy as a whole; domestic and imported sources of energy must be confronted, including the varying allocation possibilities to individual consumers. *The simultaneous weighting of all possibilities can — from the point of view of methodology — not be considered as quite developed yet.* Of course, we have a large number of methods which solve certain parts of the above problem. In the last resort, all efficiency calculations — be it a preliminary cost at the enterprise level, or the calculation of investment efficiency with a big project or the calculation of foreign trade efficiency — are solutions for only part of the problem under discussion. Such partial solutions involve some partial neglection of important economic interdependences (which, however, may be justified in some cases). The methods known and used in practice, however, are in general not quite suitable for solving problems of a scale that affect the whole of the economy.

For the sake of facilitating the presentation of the problems we will simplify the task and investigate only the case when the final use of energy — more precisely the level of production and consumption determining the use of energy — can be considered as given. Thus, we seek here only the optimum of the use of energy and of the processes directly interrelated with it (the most efficient use of resources) and disregard that, from the point of view of economy as a whole, maybe the level of energy consumption and, consequently, e. g. the production of some branch using much energy should be modified. The interrelations are — even by narrowing this task — rather complicated. To utilize resources in the best possible way, the following must be taken into account:

1. Total labour input should be minimum at the level of the economy as a whole and not only in the production and transformation of sources of energy, but also in the processes using energy. The computations are rendered more complicated because of the fact that the prices of the sources of energy and the labour necessary to produce them are not in direct proportion with each other, and thus the task cannot be solved with calculations based exclusively on prices.

2. Labour inputs should be minimized not only in respect of live labour or embodied labour continuously used, but also in respect of investments and that again not only in respect of investments aiming at the production or trans-

formation of sources of energy, but also in respect of those connected with other production processes. Again the solution of the task is made more complicated by the fact that in the sector of energy the importance of investments is preponderant: in many cases the efficiency of the production or transformation process is more or less definitely determined by the investment.

3. The most appropriate utilization of the domestic natural sources of energy as well as the economical import of energy must be ensured.

Thus the task consists in simultaneously optimizing the efficiency of investments, foreign trade, transportations and substitution of energy. The methods known and applied up till now partially solve this task only.

It is one — and a relatively simple — case of the problem of utilizing sources of energy most adequately, when the proportion in which different kinds of domestic coal should be produced must be established. Relating to this field we know of a proposal according to which the most efficient is if we exploit the different kinds of coal in direct ratio with coal deposits so that they should be exhausted at the same time.[1]

Such decision, however, would not satisfy the criterion of efficiency and could not even be considered as the first step towards the calculations of efficiency, as such "proportionate" utilization of natural endowments might involve a most wasteful use of live and embodied labour. According to another proposal, a system of accounting equivalents should be worked out for the different variants and these should be considered.[2] Indices of this type are e. g. the amount of energy needed in the given process, the investment requirement, the labour input needed for producing, transforming and transporting sources of energy, etc. It is obvious that these and similar indices may further the many-sided investigation of the problem but — at least in the majority of cases — cannot ensure the finding of the most efficient solution.

A working committee led by A. LÉVAI has applied a more developed method.[3] Here the economic implications of the utilization of different sources of energy in various processes using energy (e. g. power plants, industrial furnaces, etc.) were compared both in respect of investment and operation costs and indicated at what prices of other sources of energy — compared to the price of brown coal — could the whole process be considered from the point of view of efficiency as equivalent to the use of brown coal itself. The accounting prices thus formed gave a valuation, a possibility for classifying the various

[1] R. TARJÁN: Népgazdaságunk tüzelőanyag helyzetének távlatai (The perspectives of the fuel situation of our national economy). Közgazdasági Szemle, 1959. No. 6.

[2] Rapelin, Grosskopf, Zang, Lange. Untersuchungen über den zweckmäßigsten Einsatz der verschiedenen Energieträger. Teil I. Mitteilungen des Instituts für Energetik, Heft 9. 1958. D.D.R. (Investigations into the most efficient utilization of various sources of energy.)

[3] Irányelvek energiaigényünk gazdaságosabb fedezésére (Directives for meeting more efficiently our demand for energy). Report of an Academic Working Committee formed at the Department of thermal power plants of the Budapest Technical University, Dec. 1958. Hectographed.

sources of energy in respect to the different consumers. A decision relating to efficiency based on such a calculation is unambiguous when neither the investments nor quantities of different sources of energy available are limited; in this case the different sources of energy can be correctly confronted with *each other*. With this method, however, — if different sources of energy must be used and the quantity of a part of them as well as investments are restricted — it cannot be established what is the optimal distribution of these among the different possibilities of utilization.

There is also an opinion according to which the task cannot be solved by calculations at all. "Selection of the most advantageous variant for meeting the demand of the national economy for energy always remains a matter to be decided in the light of economic policy."[4] This statement is of course correct if it is taken in the sense that the final shaping and approval of the plan of the national economy is an act of economic policy; it is still correct if under that is understood that efficiency calculations in general cannot take into account all points of view and all factors which should be weighted. It cannot be accepted, however, if under this is meant that in respect to the most advantageous use of sources of energy decisions of economic policy can be made without well founded calculations (the whole reasoning of the author, however, points to these interpretations).

We also know of other analyses connected with the problem. Interesting and instructive calculations of efficiency are to be found e. g. in an article of V. Mihalszky, entitled: „Energiaproblémáink gazdaságos megoldásának fő útja: az olaj és gázfelhasználás növelése (The way to an efficient solution of our problems of energy: to increase the use of oil and natural gas).[5] The calculations in the article in the first place serve to support the efficiency of using oil and natural gas. They present separately the costs of the energy proper, transportation costs, the operating costs of different investments, as well as the investments necessary for the production, transformation and transportation of energy. When drawing the conclusions, the treatise only compares the economic implications of the import of coal and of natural gas and crude oil. — The computations are suited to prove that imports of oil and natural gas have great economic advantages, but do not yield information in respect to the optimal allocation of different sources of energy (and at the same time: of investments), to various kinds of energy and to different consumers if there are limited possibilities for imports of natural gas and oil — and thus, they cannot be employed for numerically laying the foundation for long-term plans.

[4] H. KNOP: Die Energiewissenschaft der DDR und die Planung ihrer künftigen Entwicklung. Verl. Die Wirtschaft, Berlin, 1960. p. 260. (Economics of energy in the German Democratic Republic and planning its future development.)
[5] Közgazdasági Szemle 1960, No. 7.

The task of efficiency calculations can be summed up briefly and on broad outlines as follows: We must choose from among different kinds of prime sources of energy producible (or importable), the production of which involve different inputs and the level of the economy as a whole (labour and other costs, investments, imports, etc.). We may further choose from among various secondary sources of energy (e. g. between electric energy and municipal gas), these latter might also be produced with the aid of different prime sources of energy. There are wide possibilities for substitution among different sources of energy. In respect of using sources of energy and also in respect of other national resources necessary to produce and transform them (e. g. investments or imports), we could only choose between certain natural or economic limits. The task must of course be solved with the least possible input at the level of the economy as a whole. Thus, it follows from the character of the task, that here we have to deal with a calculation of conditional extreme values, the solution of which — in our present knowledge — is possible with mathematical programming and, considering the rather large volume of the task, with the use of electronic computers. In consideration of the problem and the computation technics available the application of linear programming is only too obvious. Linear programming models of a similar kind — though for somewhat simpler problems — have already been worked out also in western countries; thus in the USA and the United Kingdom for the production and allocation of coal production and in France for the optimum allocation of electric energy to be produced by various kinds of thermal and hydro-electric plants. Of experiments aiming at establishing models embracing the whole of energy production and distribution, we mainly find accounts of same in the Soviet literature, where they are striving to solve regional, transportation and complex energetical problems by means of mathematical programming and electronic computers.[6]

In the course of research we have worked out a method for computing the optimal proportions of sources of energy and their optimal distribution among consumers.[7] The mathematical model for planning the most rational utilization of recources is, in principle, as follows:

We start out in the computations from the demands serving as basis for the balance of energy, i. e. from the production and services determining energy demand. These are e. g. the production of steel or cement (or the production of any other industry), the national demand for energy or the demand for coal heating of the population. We assume that the productions and services can be considered as *homogeneous consumers of energy*, i.e. the sector (pro-

[6] See e.g.: Yu. A. Kuznesow—A. P. Merenkov—L. A. Melentev—A. S. Nekrasow: Moscow, April 4, 1962 (Determination of the optimal structure of long-term balance of energy with the aid of electronic computers.) (In Russian)

[7] In building up the mathematical model B. Martos and G. Réczey have taken part.

duction or service) thus defined might be unambiguously characterized by one parameter each (e.g. production of steel in tons, the demand of the population for fuel with the number of flats or rooms), and that to these parameters belong similar unambiguously defined specific costs of energy and other costs connected with the use of energy (essentially investment and operating costs). Of course, the specific costs of energy (and other costs, too) may vary according to the technology applied — mainly according to the prime source of energy used. Besides, we consider the maximum quantity of domestic sources of primary energy available as given (upper limit, constraint).

Let us call a production (or service) carried but by a given technology (source of energy) an *activity*, denoted by $x_1, x_2, \ldots x_n$. Thus, for instance, let

$x_1$ production of electric energy from coal (kWh)
$x_2$ ,, ,, ,, from crude oil
$x_3$ ,, ,, ,, from natural gas
$x_4$ production of cement with coal (tons)
$x_5$ ,, ,, with crude oil
$x_6$ ,, ,, with natural gas
.
.
.
$x_{n-2}$ heating of flats with coal (number of rooms)
$x_{n-1}$ ,, ,, with oil
$x_n$ ,, ,, with natural gas.

Be the maximum of domestic sources of energy available, the corresponding imports and the *savings* as compared to the possible maximum utilization of domestic production as follows:

| | Max. of domestic prime source of energy | Imports | Savings |
|---|---|---|---|
| Coal ......... | $b_1$ | $y_1$ | $s_1$ |
| Oil ........... | $b_2$ | $y_2$ | $s_2$ |
| Natural gas ... | $b_3$ | $y_3$ | $s_3$ |

For specific use of energy, we have the notations:

| Production n / of | Electric energy | Cement | ... Heating of flats |
|---|---|---|---|
| 1. Coal .......... | $a_{11}$ | $a_{14}$ | $a_{1\,n-2}$ |
| 2. Oil ........... | $a_{22}$ | $a_{25}$ | $a_{2\,n-1}$ |
| 3. Natural gas ... | $a_{33}$ | $a_{36}$ | $a_{3\,n}$ |

With the above notation the following special balance of energy can be written in the form of equations:

$$a_{11} x_1 + a_{14} x_4 + \ldots + a_{1\,n-2} x_{n-2} + s_1 = b_1 + y_1 \text{ (coal)}$$

$$a_{22} x_2 + a_{25} x_5 + \ldots + a_{2\,n-1} x_{n-1} + s_2 = b_2 + y_2 \text{ (oil)}$$

$$a_{33} x_x + a_{36} x_6 + \ldots + a_{3\,n} x_n + s_3 = b_3 + y_3 \text{ (natural gas)}$$

Here, on the left-hand side of the equations we find the use of energy by "activities", as well as the "savings" mentioned and, on the right-hand side of the equations, the domestic and import sources. Each of the equations is a balance-equation of a defined source of energy (e. g. coal), and the whole system of equations is the entire balance of energy where, however, the activities ($x$), the imports ($y$) and the savings ($s$) are still unknown.

The above system of equations must still be completed. The basis for calculating the demand for energy is, namely, the volume of production (service) of each of the sectors, which is known and which must be supplied with the aid of the various sources of energy (technologies, activities). Let us denote these with "$K$", then

(electric energy) ............ $K_1 = x_1 + x_2 + x_3$

(cement) .................... $K_2 = x_4 + x_5 + x_6$

(heating for the population) ... $K_k = x_{n-2} + x_{n-1} + x_n$

It is justified as well to start from the fact that the foreign exchange available for the imports of sources of energy is not unlimited. If the maximum quantity of foreign exchange not to be overstepped is $D$, the unit price of individual imported sources of energy $d$; and the foreign exchange possibly saved as against the maximum is $z$, we obtain another equation which expresses the balance between imports of energy and the foreign exchange available for cover

$$d_1 y_1 + d_2 y_2 + d_3 y_3 + \ldots + z = D$$

The most rational (optimum) utilization of resources is achieved if, keeping the balance-ratios expressed by the above equations, the cost of all activities (considering imports also as an activity) is minimum. Thus, if the specific cost of activity $x$ is $c$:

$$(c_1 x_1 + \ldots + c_n x_n + d'_1 y_1 + \ldots + d'_n y_n) = \text{min!}$$

where $d'_1 \ldots d'_n$ denote the difference between the prices of domestic and imported sources of energy.

The equations containing the balance of energy, the balance of foreign exchange and the connections among the activities might also be written in the following manner:

$$
\begin{array}{lllll}
a_{11} x_1 + & & + s_1 & - y_1 & = b_1 \\
a_{22} x_2 + \dots & & + s_2 & - y_2 & = b_2 \\
a_{33} x_3 \dots & & + s_3 & - y_3 & = b_3 \\
x_1 + x_2 + x_3 & & & & = K_1 \\
x_3 + x_4 + x_5 & & & & = K_2 \\
\cdot & & & & \cdot \\
\cdot & & & & \cdot \\
\cdot & & & & \cdot \\
 & & & d_1 y_1 + d_2 y_2 + d_3 y_3 + z_0 & = D
\end{array}
$$

This system of equations might be written in the form of a matrix-equation as

$$\underline{\underline{A}}\, \underline{x} = \underline{b}$$

where $x$ is the vector of activities, $A$ is the matrix of coefficients belonging to the activities (the left-hand side of the equation system) and $b$ is the so-called vector of capacities (the right-hand side of the equation system.)

The so-called *objective function* expressing the minimalization of costs can be written in the form of the vectorial function:

$$\underline{c}^* \underline{x} = \min!$$

The minimalization of the function $\underline{c}^* \underline{x}$ with the constraint $\underline{\underline{A}}\, \underline{x} = \underline{b}$ can be solved with the method of linear programming — not to be discussed here. The solution yields the quantities of sources of energy to be produced at home $(b - s)$, those to be imported $(y)$ and their allocation to the different sectors using energy $(K)$, i. e. the activities $x_1 \dots x_n$

The specific costs belonging to the individual technologies (activities): $c_1 \dots c_n$ contain, beside the specific costs of energy, also the operating costs as continuous costs (with amortization included) as well as the corresponding immobilization of capital, similarly to the computations of investment efficiency — as the effect of investment costs. The operating costs can naturally be presented in different details and in different structures. The immobilized capital, too, can be calculated with differing immobilization factors, with the formulae of either simple or compound interest, etc. — that in substance does not affect the computations.

To examine the tasks connected with programming somewhat closer and to illustrate the process of computation, we have built a model that could be solved with manual methods based on the planned data for energy consumption in 1962. In the trial computations we have considered five sectors (the consumption of which amounted to about 40 per cent of the total in 1962) and two kinds of sources of basic energy, namely, solid fuels and hydrocarbons. This simplification is not irrealistic: e. g. with imports, the cost per calory of natural gas and oil are fairly near to each other, while in domestic production the separation of the costs of crude oil from that of natural gas can be only effected arbitrarily in any case. The upper constraints in the task were the planned uses of domestic sources of energy according to kinds, as well as the planned import costs of energy in the branches in question. Taking the possible savings also into account, we got a model consisting of 15 variables and 8 constraints. In the objective function the specific investment costs (resp. their part calculated for one year with immobilization of capital included), operating costs and import costs figure separately. This separation of the cost times made the application of parametric programming possible, i. e. the examination of how far, by the changes in the immobilization factor or in the conversion rate of foreign exchange the optimum program, is altered.

The result of the programming procedure — serving, of course, only purposes of illustration — showed as compared to the starting figures (the original plans) a possibility of saving 10—12 per cent.

The size of a model suitable for actual planning is naturally much bigger; the computation itself requires the use of an electronic computer. In case of such a model at least 12—15 sectors using energy and about 8—10 different sources of energy should be reckoned with.

The mathematical model surveyed in the preceding and its solution with the aid of linear programming is limited in two respects, or rather it does not adapt itself entirely to economic facts. The basic assumption of the computation method (as is to be also seen from the expression of *linear* programming) is the linear development of costs, i. e. that to the individual activities always the same specific costs belong (of energy and others). This assumption, however, obviously does not hold with either of the main cost items in question. The amount of the costs of energy depends on the volume of the energy produced (or eventually imported). It might be assumed that, for instance, with increasing domestic production of coal which must be mined even under worse natural conditions production costs will increase. On the other hand, with the growing size or better utilization of an equipment using or transforming energy, the specific investment and operating costs will decrease.

In connection with linear programming problems, this problem is well known. There exist mathematical methods also for solving such problems where the so-called cost function is not linear. In computing, however, the optimal proportions and allocation of sources of energy it would probably suffice to take up specific costs in the neighbourhood of the expectable result of programming, to control after programming whether the deviation is of a significant degree, and, if necessary, to repeat the computations on the basis of modified data.

The method of generally applied linear programming does not reckon with the *indivisibility* of certain technologies (equipment), i. e. with the fact that with a considerable part of energy used the equipment using energy can be obtained only in definite sizes (e. g. the sizes of power supplying units that can be obtained and operated economically are given). There exist mathematical methods for solving this problem, too. It seems, however, probable that when computing the allocation of energy this can be satisfied by approximating the size of the equipment, we are not obliged to obtain final and precise results. A final clarifying of both problems can, however, be effected on the basis of computations to be carried out. Besides, the model discussed is extremely flexible, by which we mean that it is suitable for the simple and quick consideration of different economic assumptions. When reviewing the structure of the model e. g. we considered only the sum of foreign exchange as limited which serves to obtain the total energy import. It may prove necessary to consider the volume of some individual imported source of energy as in itself given or to establish separate constraints for foreign exchange by countries. Under certain conditions it might be necessary to make the volume of investments available as limited, either in respect to producing basic sources of energy or the transformation of energy, or the investments serving the equipment for the final use of energy. All these constraints can be relatively easily built into the model and the implication of the constraints or of the changes in the same partly on the proportions and optimum allocation of sources of energy, partly on the total costs connected with the supply of energy can be computed. It can be established, for instance, to what degree the limitation of investments changes the demand for imports and the total costs, and inversely. It can be further established what is the effect of changing the costs or some of their items (e. g. the size of the factor for immobilization of capital) on the program (on the proportions and distribution of sources of energy), as well as on total costs.

The calculations under discussion serve to establish the optimal proportions among technologies *aiming at the same production target* and generally using different kinds of energy. Consequently, the computations are justified only in those cases where the given target might be reached with the aid of various (at least two kinds of) technologies. From which it follows that the computations can be somewhat simplified as it is not necessary to put into the equation system expressing the use of energy, the total use of same. On both the needs and sources side of the balance, i. e. both from the right and the left side of the equations the demand for energy of those consumers can be deducted which can be unambiguously operated only with one source of energy. Part of these considerations is of technological character. Besides, with some relatively modern equipment, built for the use of a specified source of energy it can also be decided without detailed calculations that reconstruction is not expedient even if the transformation for the use of some other source of energy was technically possible. — In general, everything that is identical in respect to the alternatives in question can be left out of the computations, which at the same time means the simplification of all calculations and a decrease in the number of data to be introduced into the calculations.

In the course of further preparations the main purpose of the programming must be taken into account. This main purpose can be summed up in that it must support the main directives of long term energy policy. The long term energy policy appears in the proportions of domestic and import sources of energy, more closely: in the decisions on the main investment projects and in the negotiations and decisions regarding international cooperation. It should not, therefore, be regarded as the aim of the computations to establish, with an exactness of a few per cents, in which proportions it is expedient to perform e. g. railway transportation or the production of steel with the aid of one or some other source of energy. In this respect the changes in the structure are more or less continuous, the gestation period of investments is shorter, and thus final decisions must be made later than in case of investments relating to the production and transformation of energy. The basic decisions which should be established with the aid of the model and the economic implications of which should be weighted with the same, relate to such problems as e. g. the various development concepts of domestic coal mining, their implication partly for the (investment and operating) costs involved at the level of the economy as a whole and for the demand for imported energy; or e. g. consideration of imports from non-socialist countries (in case energy imports is beyond the import possibilities from socialist countries seem necessary to be taken into account), together with their implication for the balance of foreign exchange on the one hand and for costs interpreted at the level of the economy as a whole on the other hand.

If the aims of programming are viewed in this manner, it seems that — at least with the technological variants that might be taken into account up to 1970 — the specific demands for energy of the individual sectors using energy are in general known quite precisely, with the possible exception of the population's demand for energy. Similarly, the specific investment and operating costs of the various technological alternatives seem to be fairly correctly establishable. Besides, in all probability even with these significant deviations the structure of the program will not essentially be affected.

The structure of the program depends mainly on the costs of domestic and import sources of energy, thus to which extent the results of the programming may be used is a matter of how realistic were the estimates relating to them. In the preparation, therefore, efforts should be concentrated on clarifying thoroughly and in detail the costs of domestic production of sources of energy to be expected with the different kinds of sources, the cost of import sources of energy (in foreign exchange) and the realistic conversion rates. We must be prepared for the fact, that these factors of the computations can — even with the most careful preparation — be considered as reliable only within certain rather wide limits. Since, however, these factors — following from the structure of the program — appear in the objective function, their changing and the analysis of the economic implication of the changes is possible by parametric programming.

It is worth mentioning that in the course of analysing the foundation of the long term plan of energy and investigating the method for distributing the sources of same, a working committee of the National Technological Development Board led by Sóváry — quite independent of the research going on in the Institute of Economics and following quite other lines of reasoning — has, as regards the merits of the matter, proposed the application of a rather similar method. Through a further development of the method applied by the Lévai working committee mentioned earlier, a method for the optimum allocation of sources of energy available was worked out (planned) for the main groups of consumers. Their method deviates essentially from the one described by us, in that it does not aim at simultaneously optimizing the pattern of sources of energy and their allocation to consumers, but first computes the optimum distribution of an assumed pattern among consumers and then strives to amend the pattern itself step by step. In addition, they do not reckon with constraints as regards investments and imports and do not propose the application of parametric programming. Accordingly, the mathematical apparatus to be applied can also be simpler: instead of the general task of linear programming only the simpler transportation problem must be solved. The basic reasoning of the model worked out by the Working Committee of the National Technological Development Board essentially agrees with that developed by us; even the basic data needed for the computations are the same.

Naturally, performing the computations according to the model reviewed does not exhaust the tasks of planning and of efficiency computations in the sector of energy. The computation discussed yields information for economic decisions only about the main proportions of the production and distribution of sources of energy, and even neglects several very important problems, the closer investigation of which might react on the main proportions and modify them. It is a significant characteristic feature of the model reviewed that — in accordance with the economic problems of the country — it lays great stress on the calculation of energy imports. It disregards, however, the regional distribution of energy production and utilization within the country. This conception might probably be correct in the case of Hungary, though the effect of these neglections must be examined still more closely. As against this, the Soviet paper cited examines just the problem of domestic deliveries in detail and neglects the relations to foreign trade.

It is obvious that after the first and more or less global results here, too, those more detailed computations will be needed as also deal with transportation costs, and with the complex regional utilization of different sources of energy. It is, besides to be expected that such and similar computations, will also be solved with the aid of the method of mathematical programming.

## Summary

The main phases of planning in the energy sector are:

*a)* A comprehensive examination and analysis of the main development trends;

*b)* A forecast of the development of power requirements;

*c)* The planning of equilibrium (proportionality) in the energy sector;

*d)* The planning of the most rational utilization of energy sources (economic efficiency calculation).

The main trends with regard to the production and utilization of energy are: 1. The rapid increase of power requirements caused by rapid economic expansion; 2. the technical development of energy transformation and utilization, moreover, the decrease of specific power consumption as a result of changes in the economic, particularly in the industrial structure. The latter phenomenon is closely linked to the rapid change in the pattern of the basic energy sources used, manifested mainly in the relative decrease of coal utilization and increase in that of hydrocarbons (natural gas and petroleum).

The forecast of energy requirements may — in the initial stage of planning — take place by extrapolating past developments. A more soundly based result can be attained by computing the expected power requirement by calculations of the correlation between power utilization and the main factors influencing it. A truly reliable result from the point of view of planning may, however, only be obtained from detailed planning based on the plans of the main consuming sectors and on specific figures which take technical progress into account. This latter phase of planning is already closely related to the preparation of an energy balance, setting requirements against sources.

The greatest problem from the point of view of long-range planning is to plan the most rational utilization of energy sources — that is, of calculating economic efficiency. This is the question which the paper treats in great detail. The adequate solution is by means of mathematical programing, with simultaneous consideration of the available sources, their limitations, and the various requirements. This program makes it possible to minimize the costs at the level of economy as a whole for satisfying energy requirements, by allowing the structure of energy sources to be produced (imported) and their allocation to the main consumer groups to be simultaneously computed.

The paper contains a proposal for setting up the model of the calculation, and for further research needed in order to put the method to practical use.

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