Oil Shale, Vol. 13, No. 1
pp. 65-72

ISSN 0208-198X

https://doi.org/10.3176/oil.1996.1.08

MODEL ANALYSIS OF DEVELOPMENT STRATEGY FOR THE ESTONIAN FUEL-ENERGY COMPLEX

K. TENNO
A. LAUR

Institute of Economics,
Estonian Academy of Sciences
Tallinn, Estonia

In this paper the principles of modelling of the fuel-energy complex are presented as well as the results of formation and solution of the corresponding numerical model. With the help of computer analyses the possible development scenarios of the Estonian oil-shale industry and power generation are determined for the near term as well as for the long range.

Introduction

This article describes research in the field of sustainable development of Estonian energy and power generation. The authors have continued investigations concerning the modelling of the Estonian fuel-energy complex (FEC), as previously carried out under the supervision of Prof. I. Kaganovich [1-3]. A new method has been developed and the model analysis is implemented in order to define possible development strategy for the Estonian oil-shale and power generation industries [4]. The main instrument of the analysis is the linear optimization model, describing the relations in the Estonian FEC as well as in the spheres of activity directly associated with the FEC. The variants, or options, of the optimization problems are compiled with the help of a computer program. The optimal solutions simulate the development scenarios of the Estonian FEC under different economic situations. On the basis of these scenarios a development strategy for the FEC is designed.

1. Model Description and Scheme of the Computer Analysis

The model analysis of the Estonian FEC was performed with the help of a deterministic linear optimization model. It should be mentioned that the main focus was not concentrated on optimization but on the fact that this type of model is a good method for large-scale variant calculations. Using this model it is quite easy to definitively describe all the spheres of activity of the FEC. One can follow the reactions of the output parameters of the complex by changing various input variables, and analyzing the respective

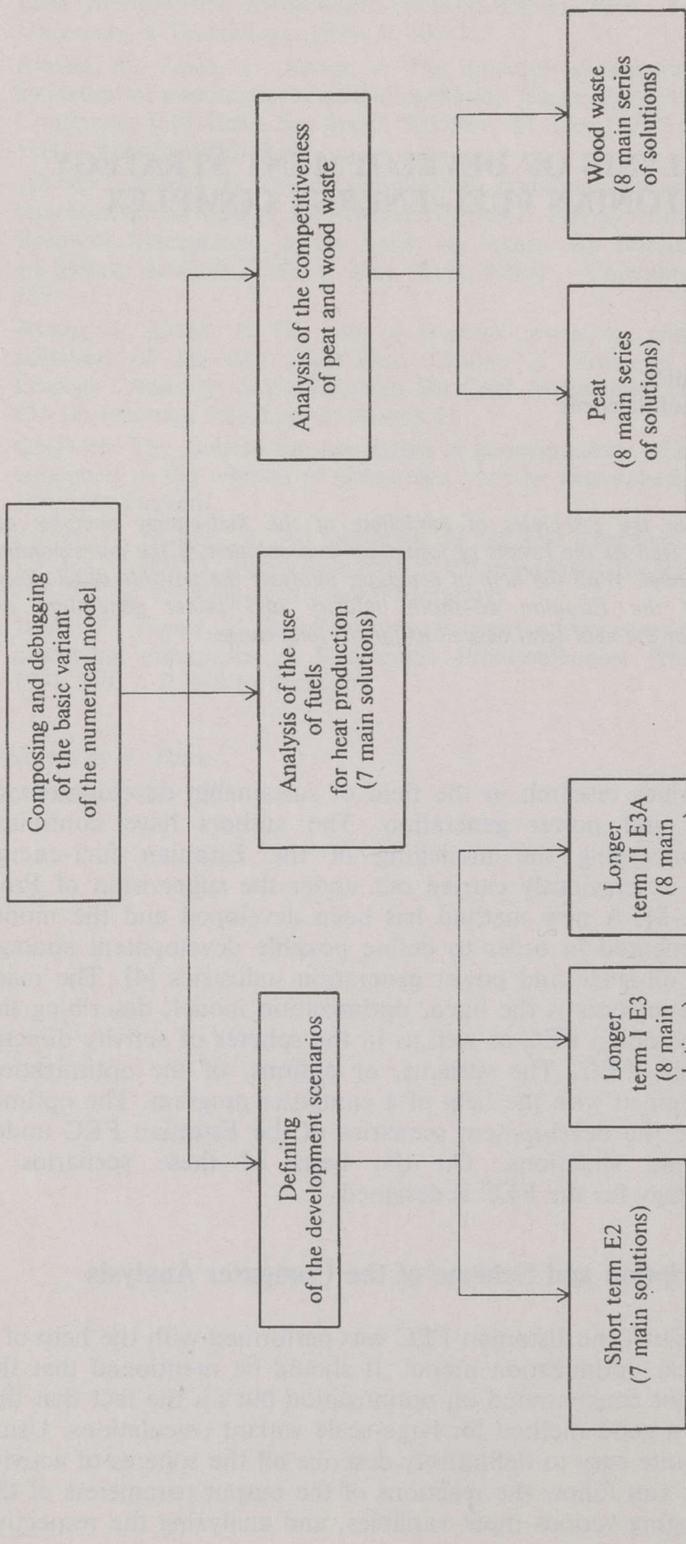

Fig. 1. Scheme of the computer analysis

optimal solutions. The input variables include the present as well as prospective initial conditions of FEC functions in the model.

The industries described in this model are oil shale mining, oil shale based power generation and heat production, alternative possibilities for power generation and heat production (peat and coal power and heat stations, peat and wood waste boilers), oil shale retorting, plus local consumption and import-export of fuels and energy.

According to this structure the main relations of the model may be presented as follows:

System of constraints:

$$\sum_{j=1}^{J} a_{ij}^{(t)} x_j^{(t)} \leq q_i^{(t)}, \ i = 1,\dots, I, x_j^{(t)} \geq 0;$$

$$\sum_{j=1}^{J} a_{kj}^{(t)} x_j^{(t)} \geq z_k^{(t)}, \ k = I+1,\dots, I+K.$$

Objective function:

$$\sum_{j=1}^{J} P_j^{(t)} x_j^{(t)} \rightarrow \min,$$

where i - identifier for the oil shale mining enterprise, $i = 1,\dots, I$;

k - identifier for the produced or imported energy resource, $k = I+1,\dots, I+K$;

j - identifier for the production technology (or of the import-export activity or of the sphere of consumption) of the energy resources;

$x_j^{(t)}$ - intensity of the production technology (or of the import-export activity or of the sphere of consumption) j of the energy resources in the year t;

$a_{ij}^{(t)}$ - production of the oil shale mining enterprise i by the unit intensity of the technology j in the year t;

$a_{kj}^{(t)}$ - production or import ($a_{kj}^{(t)} \geq 0$) and consumption or export ($a_{kj}^{(t)} < 0$) of the energy resource k at the unit intensity of the production technology (or of the sphere of consumption or of the import-export activity) j in the year t;

$q_i^{(t)}$ - production capacity of the oil shale mining enterprise i in the year t;

$z_k^{(t)}$ - forecast of the minimum demand of the energy resource k in the year t;

$P_j^{(t)}$ - processing and capital costs at the unit intensity of the production technology j or unit price (cost) of energy resource imported by activity j ($P_j^{(t)} \geq 0$) or unit price (income) of energy resource exported by activity j ($P_j^{(t)} < 0$) in the year t.

The program [5] for implementing the model on IBM AT personal computers enables one to produce individual solutions and in some cases to generate a series of solutions. In the latter case, the initial parameters of the model will be modified automatically by the chosen algorithm.

In order to achieve the goals of the investigation of the Estonian FEC, the computer analysis was planned pursuant to the methodology shown in Fig. 1.

The first step of the program development included composing and debugging of the basic variant of the numerical model. The elimination of early mistakes and the development of a satisfactory base case was followed by the main stages of program development. In the first stage, the main FEC development scenarios were defined and analyzed - one for the short term (up to 2000) and two for longer terms (from 2000 on).

In the other stages of the program, attention was concentrated on the analysis of heat production. In the second main stage, the possibilities of using different fuels in boilers were analyzed. In the third stage, the competitiveness of local fuels (peat and wood waste) was estimated.

In the first two stages, the program produces individual solutions. In the third stage, the series of solutions are generated. Serious attention is given to the analysis of dual solutions.

2. Construction of the Numerical Model

The model describing the FEC was developed on the basis of an optimization problem consisting of the following blocks:

M - "Mining" - oil shale mining, peat and wood waste production (10 objects or technologies);

E - "Energy System" - power stations with their service systems (7 objects or technologies);

H - "Heat Production" - heating network in Tallinn and groups of boilers (19 objects);

R - "Retorting" - oil shale retorting and upgrading (3 objects or technologies);

I - "Import-export" - import and export of fuels and energy (7 activities);

C - "Consumption" - consumption of fuels and energy outside the FEC (5 spheres of activity).

The constraints for the base case of the numerical model were obtained from data on production, import-export and consumption of fuels and energy in 1993 and 1994, as well as the actual technical and economic indices for the components of the Estonian FEC. The alternatives for the existing oil-shale, heavy fuel oil and gas power plants are coal and peat stations.

Minimization of production costs was chosen as the objective function. In our opinion, this expresses the best principle for sustained development. The production costs include conversion costs as well as investments for renovation, reconstruction or expansion of production. A wide range of investment amounts are considered - beginning with indispensable expenditures in the short term to the full renovation of the energy system in the long term. In the "Energy System" block, the production costs are calculated for three versions: with minimal investments (E2) for the base case and for the short term, and with maximal (E3) and moderate (E3A) investments for the long term. All the costs in the future are discounted. An interest rate of 9 % is used for investment amortization.*

In the "Mining" block, two levels of oil shale production are considered: 12 and 15 million tonnes per year (M1, M2). These two production levels distinguish between options where various mining enterprises will continue to work at varying capacities, and some will be closed. In the latter case, the costs connected with liquidation and/or conservation of mines should also be taken into account. According to the calculations of "Eesti Põlevkivi", the Sompa and Kohtla Mines will be closed in the case of minimal oil shale production (M1), and Tammiku and Ahtme Mines will be conserved.

3. Analysis of Modelling Results

After implementing the aforementioned program scheme, one can follow the developments of the Estonian FEC with presumed initial conditions over different periods of time. The most complicated problem, which also has a high degree of uncertainty, is the determination of adequate conditions for the period under consideration. Of course, the shorter this period, the easier it is to ascertain these conditions. The model analysis should be continued, taking into account the changing economic situation and other new information.

The authors are of the opinion that analysis of the results of the described optimization problem enables one to define the main principles for the development of the Estonian FEC, as listed below.

It is useful to keep the annual oil shale mine production at a level of approximately 15 million tonnes in the immediate future. This would allow for the generation of enough electric energy for Estonia's domestic use (5-6 TWh a year). Under certain favorable conditions, some of this electricity could even be exported. The oil shale-based electricity will remain considerably cheaper than coal- and peat-based electricity in the near future. This advantage will persist as long as only moderate investments (US $140-180 millions) are made for keeping existing oil shale power plants and oil shale mines in operation.

The complete renovation of the Estonian oil shale based FEC would require much larger investments (around US $1-2 billions). Such investments would cause a significant increase in oil shale prices, as well as the prices of electricity generated from the oil shale. Under this alternative, the price of oil shale-based electricity may become equal to or even greater than the coal-based electricity. That would mean that the advantages of power generation using oil shale will be lost when compared to other fuels. According to the results of the model analysis, coal-based electricity will be competitive with oil shale-based electricity when the production cost of

* Discount rate and interest rate are equal and they are corresponding to the conditions of the World Bank energetics loan.

the latter rises to a level of 65-70 sents/kWh (depending on the coal price).

The feasibility of electric energy exports depends on the electricity prices in Estonia and neighbouring countries. In order to define this potential, a relevant market study is urgently needed. It is necessary to know the price at which it is possible to sell (export) electric energy. Without this information it is impossible to justify essential investments in oil shale power stations.

Shale oil exports have been beneficial at the present oil shale prices, but shale oil production may be reduced due to a decline in lump oil shale production. The decline in electric energy consumption and export has had a negative effect on oil-shale mining. It has caused a decline in lump oil shale production. The shale oil production is also affected by the rising oil shale prices. Shale oil export has been beneficial since its production price has been lower than the import price of heavy fuel oil.

The oil shale imported from Russia has of course been useful, since this imported shale has usually been lower cost than domestic production. If the price of imported oil shale is the same or higher than that of domestic oil shale, then the situation would change essentially. If there is not enough domestic oil shale for local electric energy consumption, or there are favourable opportunities for electric energy export in the near future, the importation of oil shale may be more effective in the near term than starting the production of coal- or peat-based electricity.

Percentage Increase in the Cost of Heat after Substitution of an Alternative Fuel

Fuel to be substituted	Substitute					
	Shale oil	Heavy fuel oil	Waste wood (EEK/m^3 75)	Natural gas	Peat	Waste wood (EEK/m^3 100)
Coal	5.8	6.7	20.2	22.4	33.2	33.2
Shale oil		0.8	13.6	15.7	25.8	25.8
Heavy fuel oil			12.6	14.7	24.8	24.8
Waste wood (EEK/m^3 75)				1.9	10.8	10.8
Natural gas					8.8	8.8
Peat						0

Existing mining capacities obviously provide a sufficient amount of oil shale for domestic electric energy consumption until 2000, and even longer. As a result, no concrete decisions have been made for building new mines (or extending the lives of old ones). Nevertheless, now is the time to think about the substitution of oil shale with other fuels for long range applications. The model analysis has shown that the preferred option under the condition of oil shale shortage is the coal-fired thermal power station. With current average fuel prices (coal EEK/t 600, peat EEK/t 200) the advantage of coal in comparison with the peat option is 16-24 %. This difference may increase considerably in the future since the price of coal is relatively stable but peat prices may continue to rise.

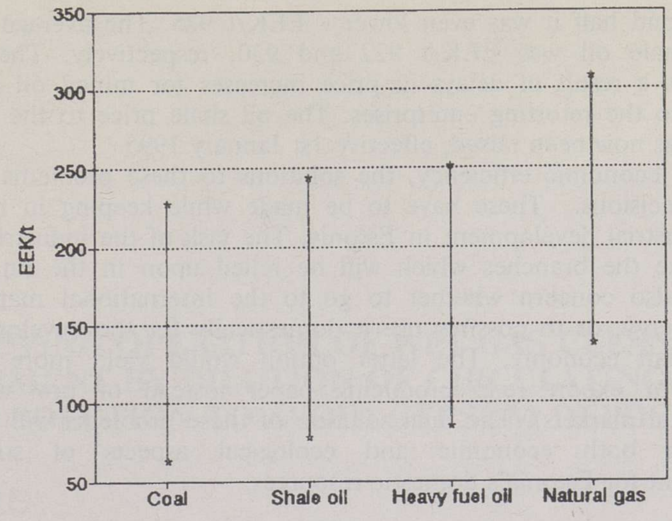

Fig. 2. The marginal prices of peat relative to other fuels

In order to perform a more detailed analysis of the peat option, competent investigations of possible peat production, as well as objective forecasts of the peat price, are needed.

The cheapest variant for heat production is the coal-based one. It is followed by shale oil and heavy fuel oil. The substitution of coal with other fuels in the existing boilers will cause an increase in the cost of heat as shown in the Table above.

Peat and wood waste are not very competitive in heat production. The results of the model analysis for estimating the competitiveness of peat as compared to alternate fuels is illustrated in Fig. 2. In this Figure, the bottom margin of the peat price (if existing boilers are converted to firing peat) shows that even the substitution of natural gas - as the most expensive fuel - is effective only if the peat price is not higher than EEK/t 140. The absolute competitiveness (in the case of building new boilers) of peat and waste wood is also low (see the upper margin of the peat price in Fig. 2). The general problem of domestic fuel competitiveness is a special question which is not discussed in this article.

Under the inevitable conditions of price escalation, it is very important to establish government industrial policies and fix their role in regulating prices. This will establish the economic competitiveness of the entire FEC complex. The prices of oil shale and electric energy are without doubt the most important. The industrial policy must determine whether to let them be determined by free markets or to regulate them for government-defined economic purposes. Unfortunately, these purposes are not quite clear yet. If the oil shale price continues to rise, then the production of shale oil for use as a fuel oil will soon become questionable - the shale oil price will soon be higher than the average price of imported heavy fuel oil. According to the data of the State Statistical Office the weighted average price of heavy fuel oil in Estonia in the first half of 1994 was EEK/t 995, in the second half it was even lower - EEK/t 925. The average price of realized shale oil was EEK/t 922 and 930, respectively. The current situation is a result of delays in price increases for mined oil shale, as delivered to the retorting enterprises. The oil shale price to the retorting facilities has now been raised, effective 1st January 1995.

Besides economic efficiency, the solutions to these problems are also political decisions. These have to be made while keeping in mind the whole industrial development in Estonia. The task of the industrial policy is to define the branches which will be relied upon in the future. The decisions also concern whether to go to the international market with electric energy, or to possibly use it domestically for the development of the Estonian economy. The latter option would yield more valuable products for export (e.g. producing paper instead of raw wood for international markets). The final solution of these problems will be made considering both economic and ecological aspects of sustainable development for Estonia's domestic resources.

ACKNOWLEDGEMENTS

This research was supported by Grant No. 1547 of the Estonian Science Foundation.

REFERENCES

1. *Kaganovich I.* Negative consequences of the use of natural resources: the economic aspect // Proc. Estonian Acad. Sci. Soc. Sci. 1992. V. 41, No. 2. P. 95-110 [in Russian, summary in Estonian and English].
2. *Barabaner N. I., Kaganovich I. Z.* Oil shale production and power generation in Estonia. Economic and environmental dilemmas // Energy Policy. 1993. No. 6. P. 703-709.
3. *Barabaner N., Kaganovich I., Laur A.* Modelling and analysis of the use of natural resources in mining (on the example of the oil shale complex) // Preprint No. 27, Inst. of Econ., Estonian Acad. Sci. Tallinn, 1990, I (65 P.), II (53 P.) [In Russian].
4. *Laur. A., Tenno K.* Modelling of development scenarios of the Estonian fuel-energy complex // Proc. Estonian Acad. Sci. Soc. Sci. 1995. V. 44, No. 1. P. 21-35.
5. *Laur A.* Interactive analysis of the linear optimization problems under uncertainty // Analysis of the Economic and Ecological Problems / Inst. of Econ., Estonian Acad. Sci. Tallinn, 1986. P. 179-188 [in Russian, summary in Estonian and English].

Presented by I. Õpik
Received May 4, 1995