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OIL SHALE IN ESTONIAN POWER INDUSTRY

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The purpose of this study was to create a simple mathematical model to describe as well as possible the structure of a mining enterprise. The model differs from previous ones in some methodical complements and describes better the current situation in the oil shale industry. In the model expenses are divided into variable and fixed costs for each mining enterprise. Several calculations have been made to optimize sale of oil shale for both power industry and oil producers.

In Estonia the main sources of primary energy are oil shale, peat and other fuels of biological origin. The most important among them is oil shale. Over 90 % of requisite energy is produced by two main power plants burning oil shale. In 2000 the share of oil shale in the balance of Estonian primary energy was 57.4 % (Fig. 1), 69.7 % of the electricity and heat was produced from oil shale (Fig. 2).

Estonian Government and Parliament have made a strategic decision to continue oil-shale-based energy production till the year 2015 and to maintain its competitiveness for at least 25 years. In 2002 a new Master Plan of Estonian Fuel and Power till the year 2035 was worked out. The decision to

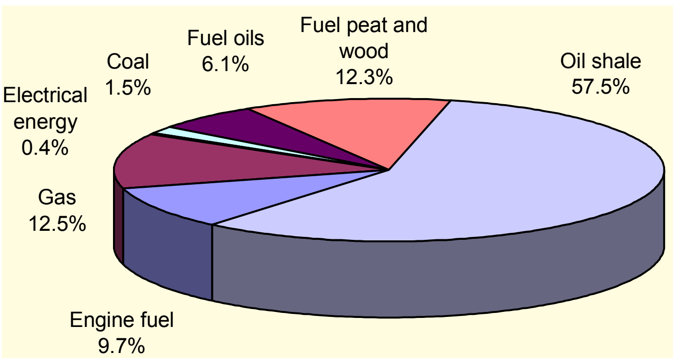

Fig. 1. Balance of primary energy in Estonia in 2000

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utilize oil shale was determined by the need to use up the resources and capacities of currently operating mines and power plants, and also by the high cost of alternative solutions. Import of electricity from Russia or Lithuania is a current alternative. However, one has to consider that the price of electricity from Russia is not transparent enough to build our state energy policy on. There are also no other trustworthy ways to assure certainty and independence of providing state with electric energy.

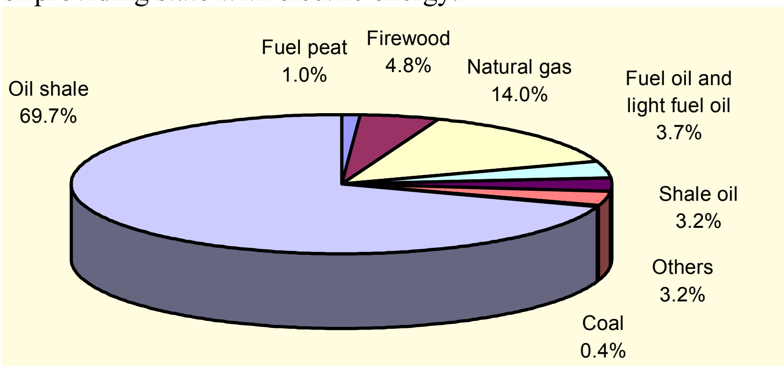

Fig. 2. Estonia's consumption of fuels for producing electricity and heat

Though competitiveness of the oil-shale-based power industry is ensured, however, oil production is operating on the boundary of its profitability: in the world market oil price ranges from 25 to 35 USD/bbl. If expenses of oil shale mining are near 100 EEK/t, the traditional oil industry could operate satisfactorily at oil price over 30 USD/bbl*. In reality oil price is not constantly that high, it changes in short time for several percents. In September 2002 it was more than 30 USD/bbl, in the beginning of November 25 USD/bbl with falling tendency. Fluctuating price makes oil a product of high risk level for the mining industry. Oil producers are interested in higher flexibility of oil shale extraction, for example shale should be mined highly selectively. However, this demands some extra capital and, besides, mining losses would be greater.

Nevertheless, oil producers are quite optimistic about the future. New technologies are studied and selected. According to the forecast, the present ratio power industry versus oil production 85 : 15 will be 50 : 50 after fifteen years.

Consumers

According to the field of use, oil shale as a raw material can be divided into fuel oil shale and oil shale for oil producers. The first of them is used in power plants to produce energy. The main consumers are Estonian and Baltic power plants near the towns of Narva and Ahtme, and Kohtla-Järve

* According to studies of Department of Mining of TTU (prof. E. Reinsalu).

power plant in the town of Kohtla-Järve. Main oil producers are *Viru Oil* Ltd and *T.R. Tamme Auto* Ltd at Kiviõli. *Kunda Nordic Cement* is also a stable consumer, but its capacities are rather low, about 200 thousand tons a year (Fig. 3). Different consumers have different demands for oil shale calorific value. Power plants use oil shale with calorific value of 8.4–9 MJ/kg, oil producers use shale with the value above 11.3 MJ/kg (Fig. 4).

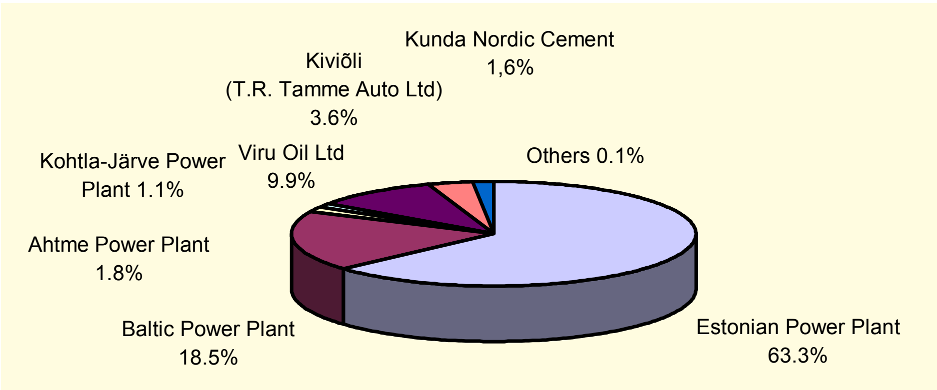

Fig. 3. Oil shale consumers in 2000

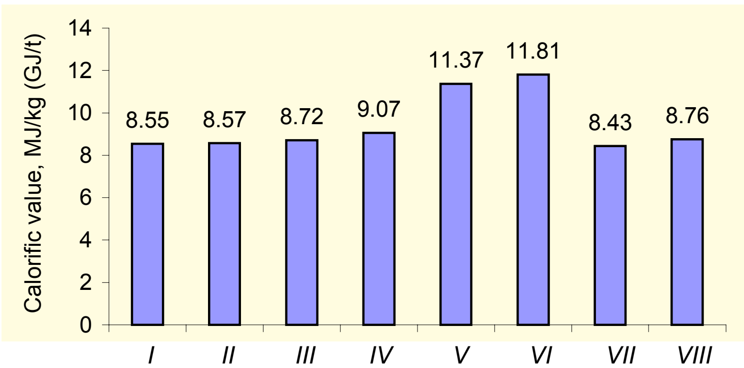

Fig. 4. Consumers' demands in oil shale quality in 2000: *I* – Estonian Power Plant; *II* – Baltic Power Plant; *III* – Ahtme Power Plant; *IV* – Kohtla-Järve Power Plant; *V* – *Viru Oil* Ltd; *VI* – Kiviõli (*T.R. Tamme Auto* Ltd); *VII* – *Kunda Nordic Cement*; *VIII* – others

Mines

In 2002 two mines (*Viru* and *Estonia*) and two open casts (*Narva* and *Aidu*) were operating. *Viru*, *Aidu* and *Estonia* gave both kinds of oil shale. *Narva* open cast produced only fuel oil shale (Fig. 5).

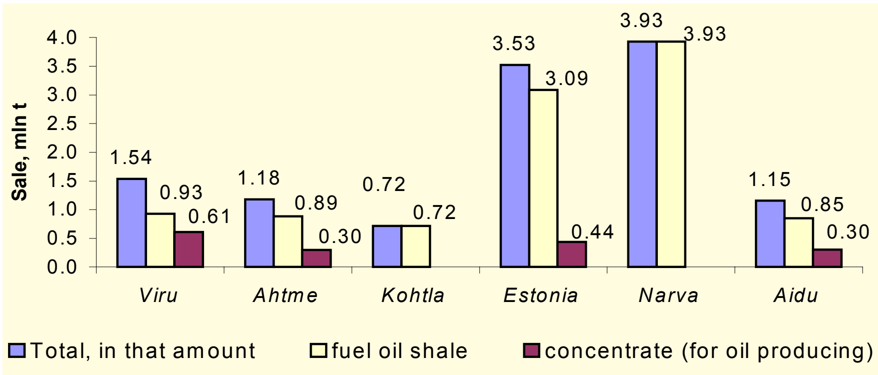

Fig. 5. Sale of oil shale by enterprises in 2000

Short Overview on Previous Papers

Optimization of oil shale mining and power generating systems has been a continuous process studied by a number of scientists.

For example, a study made by oil shale economists about the usage of fuel oil shale resources analyzes the modeling of the energy system development [2]. This study in the field of sustainable development continues the series of modeling the fuel-energy system started at the Institute of Economics at Tallinn Technical University. Different versions of development have been studied and new scenarios worked out on the basis of replenished data. Problems of the usage of local fuels (peat, wood) to produce thermal energy have been considered. The main strategic principles of the Estonian fuel-energy system have been developed basing on modeling results.

Within the framework of the program "Atmosphere, Climate Changes, Energy" the optimal level of using oil shale in power plants has been studied by the researchers of Tallinn Technical University and Stockholm Environment Institute Tallinn Center [3]. Global changes in natural ecological systems, caused by climate, and emission of greenhouse gases in Estonian industry, especially from oil shale power engineering and transportation, were analyzed.

Professor E. Reinsalu has been engaged in economical-mathematical optimization of the mining industry since the seventies of the last century, first at the Estonian Branch of Skotchinsky Mining Institute, later at the Mining Department of Tallinn Technical University [4].

Setting a Task

In connection with opening the Estonian energy market in the near future, the essential task is to keep the price of oil shale low. Such optimization calculations have been made continuously, but due to unpredictability of the economical situation, they should be carried on.

One part of restructuring *Eesti Põlevkivi AS* (*Estonian Oil Shale* Ltd) is concentrating and closing down mining enterprises to use their maximal production with minimal expenses. During such changes several circumstances should be considered:

- Different mines sell different kinds of oil shale in different proportions; enterprises without concentration plant (*Narva* open cast) sell only fuel oil shale while enterprises with concentration plant produce both fuel and oil-producing oil shale although the proportion of the latter differs; *Estonian Oil Shale* Ltd has to ensure clients oil shale of proper quality
- Oil shale bed in different mine fields is different; closing down enterprises must not affect the provision of the consumers

In such a complicated system simple solutions are hard to find. Changing of each element changes significantly the whole system. Following all the variations is complicated but possible when using computing technology. The present study was made without considering significant changes in the structure of trade oil shale. It means that if one enterprise sells both fuel and oil-producing oil shale and these trade sorts have a formed quality, this enterprise is considered in the model exactly with those data. Practically some technological developments are possible and probably even necessary. Some possible changes involve reconstruction of concentration plant of the *Estonia* mine for selling only fuel oil shale, or practicing high-selective open-cast mining for getting oil shale for oil production only. Considering such changes in the model is possible if the effects on expenses and quality are known.

Methodology

The model represents simultaneous inequalities solved with the procedure Solver of Microsoft Excel (Table 1). The goal of the model is to get the maximal total profit. For that purpose the profit of each single enterprise has to be maximized, and that can be done by reducing fixed expenses. The latter is possible by increasing the productivity.

Constraints in such optimization are:

- Average calorific value of realized oil shale must not be reduced
- Power plants must get required amount of energy

Selling amounts of oil shale are set proceeding from calorific value and required energy amounts

Some simplifications were made at optimizing:

- Transportation expenses to customers are not included
- Expenses on closing of mines are not included
- Real volumes and data are taken for setting constraints
- The price of oil shale for every enterprise is taken for the same, actual differences between enterprises are not taken into account

Table 1. **Example of Calculation Table**

Data per year	*Viru*	*Estonia*	*Narva*	*Aidu*	Total	Min.	Max.
Production, million t	1.800	4.299	4.454	1.521	12.074		
Production, min, million t	0.000	0.000	0.000	0.000	0		
Production, max, million t	1.800	5.000	5.000	2.000	13.8		
Energy production, PJ	9.46	32.17	38.04	9.35	89.02	89.00	89,02
Calorific value of fuel oil shale, GJ/t	8.71	8.55	8.54	8.35	8.5400	8.54	
Concentrate, million t	0.71	0.54	0.00	0.40	1.650	1.650	2,00
Share of concentrate, %/100	0.396	0.125	0.000	0.264	0.12		
Labor consumption ratio, 1/million t	422	446	247	380	361		
Number of employees	760	1917	1100	578	4354		
Fixed cost, million EEK	77.47	191.98	175.07	66.06	510.59		
Variable cost, EEK/t	52.14	57.16	44.62	60.95	52.26		
Cost price, EEK/t	95.18	101.81	83.92	104.39	94.55		
Production costs, million EEK	171.32	437.72	373.79	158.74	1141.56		
Share of fixed costs, %/100	0.5	0.5	0.5	0.5	0.45		
Price of fuel oil shale, EEK/t	124.3	124.3	124.3	124.3	124.3		
Price of concentrate, EEK/t	109.8	109.8	109.8	109.8	109.8		
Income from sales of fuel oil shale, million EEK	135.08	467.83	553.64	139.17	1295.72		
Income from sales of concentrate, million EEK	78.31	58.83	0.00	44.03	181.17		
Total income from sales, million EEK	213.40	526.65	553.64	183.20	1476.89		
Profit, million EEK	42.08	88.93	179.85	24.46	335.33		

Solution

Four different scenarios in two groups are presented (Table 2):

- Oil shale for oil producers is sold at the actual level of the year 2000
- Oil shale for oil producers is sold in quantities profitable for *Estonian Oil Shale* Ltd, which means that a minimum constraint is not set

Table 2. **Comparison of Scenarios**

Data	Actual	**1**	**2**	**3**	**4**
Production, million t	11.728*/12.048**	12.074	11.726	12.046	11.409
Energy production, PJ	86.87*/89.02**	89.02	89.02	89.02	89.02
Calorific value of fuel oil shale, GJ/t	8.56	8.54	8.56	8.56	8.55
Concentrate, million t	1.582*/1.650**	1.650	1.327	1.650	0.991
Share of concentrate, %/100	0.13*/0.14**	0.12	0.11	0.12	0.08
Labor consumption ratio, 1/million t	413*	361	342	362	333
Number of employees	4949*	4354	4005	4355	3800
Cost price, EEK/t	103.90*	94.5	88.9	94.0	90.3
Production costs, million EEK	1218.52*	1141.5	1042	1144	1030
Income from sales, million EEK	1473.57**	1476.9	1438.3	1473.4	1403.7
Profit, million EEK	255.05***	335.3	395.3	329.4	373.6

* – according to production, ** – according to sale,
*** – difference between sales income and production costs.

The dual values obtained give very important information about behavior of the whole oil shale mining enterprise. They show changes in expenses if one unit sets some constraints. At raising the production of *Viru* mine every next ton would reduce production expenses by 37.8 kroons. Producing one ton of concentrate costs 141.8 kroons, which is the real cost of that sort of oil shale. Maybe this number needs some explanation. If the average price of 1 ton oil shale is 94.55, how the price of concentrate can be 141.8? The point is that concentrate cannot be produced separately, without increasing the production of fuel oil shale. However, that increases mining expenses. If we take 109.8 kroons for the average price of concentrate, we state that this sort of oil shale is paid by producers.

Scenario 1

To maintain current production we cannot close any more enterprises. The question is why *Narva* open cast is not working at full production capacity although it has the lowest production cost. Why *Aidu* open cast has so high production capacity although *Aidu*'s is the most expensive to maintain. The decisive factor is to keep the rate of producing concentrate. It cannot be obtained from *Narva* open cast; *Viru* and *Estonia* mines together also do not grant the production needed. So, the lacking part has to be obtained from *Aidu*. The reasons why *Estonia* and *Narva* mines work at underload, and the lack must be taken from *Aidu* are as follows:

- In the small enterprise *Aidu* cost price depends more on production capacity than that of *Estonia* or *Narva* mines
- Fuel oil shale mined in *Aidu* has lower calorific value than customers' need. Selling possibly more oil shale of demanded calorific value is, of course, more profitable, and selling in addition to concentrate certain amounts of *Aidu* low-calorific shale seems to be a good possibility

Scenario 2

shows what happens if production of oil shale for oil producing is set free. It offers the possibility to produce as much shale as profitable. The profit would exceed that of the previous scenario by about 60 million kroons. That would also be the best solution considering the technology in use.

In these scenarios other mines had to compensate low calorific value of *Aidu* oil shale. What will happen if the calorific value there will be exactly as high as needed for power plants? Changes in the cost price for that case are not considered. The possibility to maintain the amount of oil shale needed for oil producing is also dealt with.

Scenario 3

The only change compared with Scenario 1 is that the production is redivided between the enterprises, and the profit is somewhat less than in Scenario 1.

Scenario 4
It handles the possibility of closing *Viru* mine. Calculations show that the profit reduces by about 20 million kroons compared to Scenario 2.

Conclusions

- Oil shale producing for oil producers at the current level and structure is not profitable, as production costs exceed sales income.
- Granting fuel oil shale quality has reached the limits of demand. For planning the future it is expedient to consider changes in production structure inside subsidiary companies, especially when oil shale selling for oil producers is to be maintained at the current level. Calculations show that it would be practical to reduce the output of oil shale for oil producing.

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