OIL SHALE 1994, Vol. 11, No. 3

https://doi.org/10.3176/oil.1994.3.07

K. HABICHT

OIL SHALE MINES AND THEIR REALIZABLE PRODUCTION

The production of Estonian oil shale depends on its marketing opportunities. The realizable production is a function of the oil shale price, which in turn depends on production costs. The latter are dependent on which mines are producing oil shale and on the volume of production.

The purpose of the present article is to analyze which mines should operate under various realizable production scenarios and what should be their annual output so that the total cost of oil shale production (including maintenance at idle mines) is minimized. This paper is also targeted at observing the change in the average production cost per ton of oil shale depending on the realizable output.

The calculations are based on data for the first four months of 1993, as collected by N. Barabaner (Estonian Academy of Sciences, Institute of Economy). The data include the total production volume and production cost from the mines of RE "Eesti Põlevkivi" (State Enterprise "Estonian Oil Shale"). They also project expenses from mine closings in case of conservation. The latter costs were allocated among mines in direct proportion to their respective number of employees.

1. Statement of the Problem and Initial Data

Define the problem as the economic optimization of the distribution of annual realizable oil shale quantity D_Σ between mines $i = 1,\ldots,9$, i.e. the pursuit of minimum total mining (and, if necessary, closing) costs. Let the rated capacity of a given mine be D_i ton per year. The variables sought are the utilization coefficients x_i ($0 \leq x_i \leq 1$) of the individual mines.

Assume that the production costs, denoted by a_i, are linearly dependent on the annual output $D_i x_i$ of the mine.

$$A_i = x_i q_i C_i + (1 - q_i) C_i, \qquad (1)$$

if $k_i \leq x_i \leq 1$,

$$A_i = P_i, \qquad (2)$$

if $x_i = 0$,

where C_i - production costs in case of nominal capacity of mine i, kroons a year;

q_i - conditionally changing part of mining costs;

k_i - coefficient restricting the minimal annual production of an operating mine i;

P_i - expenses for shutting down mine i, kroons a year.

If $x_i=1$ (when a mine is operating at full capacity), then production costs $A_i=C_i$ and if the mine is idled, the corresponding costs (maintenance costs and unemployment benefits) are P_i.

Production cost a_i is expressed as follows:

$$a_i = q_i \frac{C_i}{D_i} + (1-q_i)\frac{C_i}{D_i} \cdot \frac{1}{x_i}.$$

Let

$$\frac{C_i}{D_i} = a_{i,o},$$

then

$$a_i = q_i a_{i,o} + (1-q_i)\, a_{i,o} \frac{1}{x_i},$$

where $a_{i,o}$ - oil shale cost in an operating mine i at its full capacity, kroons per ton.

If one consider that conventionally $q_i = q = 0.5$, then

$$a_i = \frac{a_{i,o}}{2}(1+\frac{1}{x_i}).$$

If to minimize the costs of producing oil shale into an objective function:

$$\sum_i A_i \longrightarrow \min,$$

on condition that

$$\sum_i x_i D_i = D_\Sigma^{(j)},\ j = 1,\ldots,11,$$

where the following eleven annually realizable amounts of oil shale have been studied

j	1	2	3	4	5	6	7	8	9	10	11
$D_\Sigma^{(j)}$ (mill.t)	18	17	16	15	14	13	12	11	10	9	8

Table 1. **Initial Data of the Problem**

Parameters	Mines								
	Sompa $i=1$	Viru $i=2$	Tammiku $i=3$	Ahtme $i=4$	Kohtla $i=5$	Estonia $i=6$	Sirgala $i=7$	Narva $i=8$	Aidu $i=9$
Rated capacity (D_i), mill.t per year	1.20	1.86	1.35	2.00	1.10	5.40	3.60	2.50	3.10
Production cost per year (C_i), EEK mill.	54.1	76.3	52.3	90.8	34.3	270.0	108.8	89.8	118.4
Expenses for closing down a mine (P_i), EEK mill./a year	6.0	10.0	-	10.0	-	24.0	11.0	6.0	10.0
Minimal expected annual output (k_iD_i), mill.t	0.60	1.30	0.90	1.20	0.75	3.40	2.50	1.80	2.40
Cost (a_i), EEK/t, if the annual output (mill.t) is:									
D_i	45.1	41.0	38.7	45.4	31.2	50.0	30.2	35.9	38.2
k_iD_i	67.6	49.8	48.4	60.5	38.4	64.7	36.9	42.9	43.8

Notes:

1. In case the mines of Tammiku and Kohtla, where the resources will be exhausted in a short term, it is not expedient to include the closing costs.

2. The minimum estimated annual output is, as a rule, determined by the so-called minimum version of total output (12 million tons a year) planned by RE "Eesti Põlevkivi" ("Estonian Oil Shale").

Table 2. **Annual Output of Mines Depending on Total Annual Output, D_Σ**

Mine	Potential annual output, mill.t	D_Σ (mill.t)										
		8	9	10	11	12	13	14	15	16	17	18
Sompa	0.60-1.20	-	-	-	-	-	-	-	1.20	1.20	1.20	0.95
Viru	1.30-1.86	-	-	-	1.30	1.70	1.50	1.86	1.86	1.86	-	-
Tammiku	0.90-1.35	-	-	-	-	-	-	-	-	1.35	1.35	1.35
Ahtme	1.20-2.00	-	-	-	-	-	1.20	1.84	1.64	1.29	-	-
Kohtla	0.75-1.10	-	-	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Estonia	3.40-5.40	-	-	-	-	-	-	-	-	-	4.15	5.40
Sirgala	2.50-3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60
Narva	1.80-2.50	2.00	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Aidu	2.40-3.10	2.40	2.90	2.80	2.50	3.10	3.10	3.10	3.10	3.10	3.10	3.10
Average cost of oil shale, EEK/t		43.1	40.4	39.6	40.4	38.7	40.2	38.9	39.2	39.5	42.1	41.2

The oil shale market, and consequently also the total annual output, may change. In that case, one cannot afford to close down a mine temporarily and open it again when the need for oil shale grows. Thus:

if $x_i^{(j)} = 0$

then it shall be

$x_i^{(l)} = 0$

either in case of every $l=1,\dots,j-1$
or in case of every $l=j+1,\dots,11$.

It is obvious that for a given total output objective the mines with lower unit cost are the ones to be kept in operation in order to minimize production costs. However, the restrictions on the annual output, the last-mentioned condition and the cost of closing down mines also have a significant impact.

Initial data for the problem are presented in Table 1.

2. Solutions of the Problem and Conclusions

The solution of the oil shale cost problem gave the results presented in Table 2.

The solutions are represented by the average cost of oil shale at different realizable outputs (Table 2; Figure 1). Although the initial data and thus also the annual outputs of mines are approximate values, two conclusions can be drawn from them.

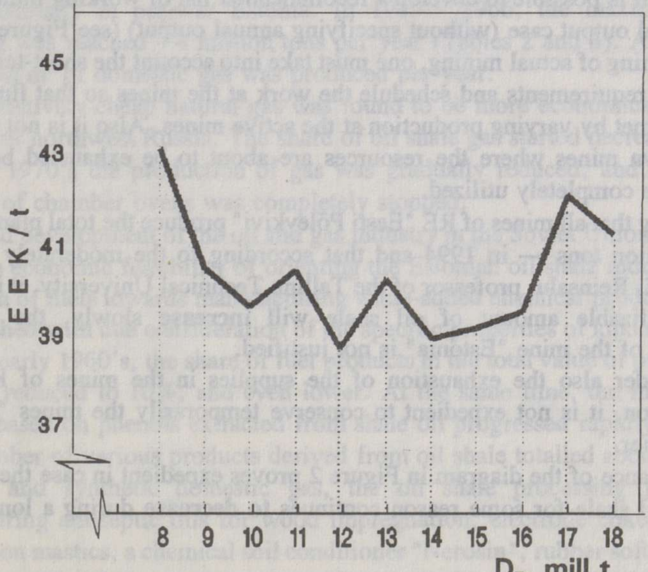

Fig. 1. Average cost of oil shale at various production levels

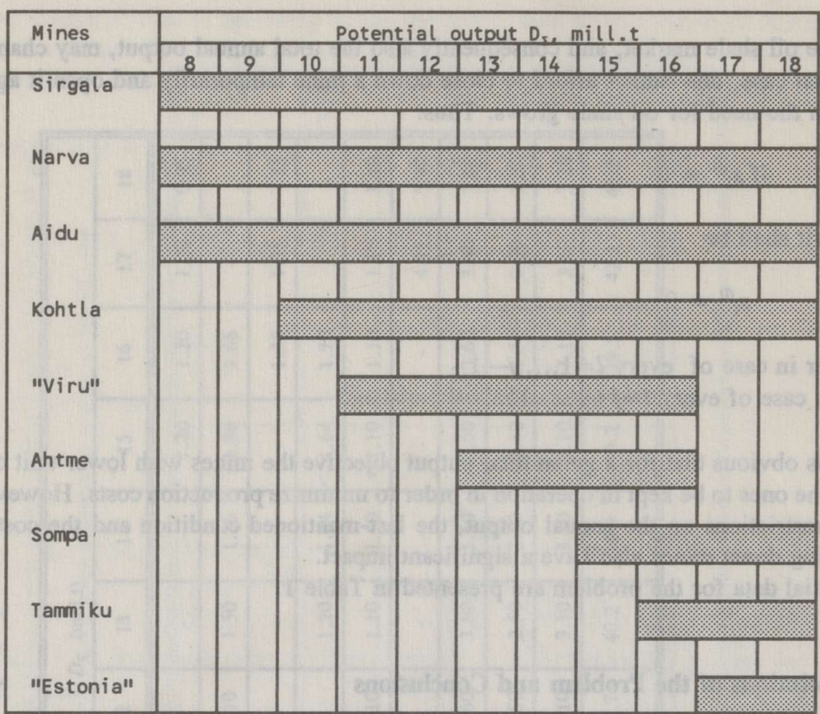

Fig. 2. Recommended working mines for various total outputs D_Σ

First — average production costs (EEK/t) in oil shale mines are not very dependent on their total output.

Second — it is possible to develop a recommended list of working mines for each potential total output case (without specifying annual output) (see Figure 2).

In the planning of actual mining, one must take into account the short-term forecast for oil shale requirements and schedule the work at the mines so that fluctuation in demand are met by varying production at the active mines. Also it is not reasonable to close down mines where the resources are about to be exhausted before their resources are completely utilized.

Considering that all mines of RE "Eesti Põlevkivi" produce the total planned output — 14.8 million tons — in 1994 and that according to the moderately optimistic forecast by E. Reinsalu, professor of the Tallinn Technical University, it is expected that the realizable amount of oil shale will increase slowly, the temporary conservation of the mine "Estonia" is not justified.

If to consider also the exhaustion of the supplies in the mines of Kohtla and Tammiku soon, it is not expedient to conserve temporarily the mines "Viru" and "Ahtme" either.

The observance of the diagram in Figure 2 proves expedient in case the realizable amount of oil shale for some reason continues to decrease during a longer period of time.

Presented by E. Reinsalu
Received April 18, 1994

Estonian Academy of Sciences,
Institute of Economy
Tallinn, Estonia