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Economic Model of Oil Shale Flows and Cost

TAUNO TAMMEOJA

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Declaration:

Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree or examination

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Põlevkivi kaubavoogude ja hinna majandusmatemaatiline mudel

TAUNO TAMMEOJA

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CONTENTS

Terms

Concentrate or concentrated oil shale or technological oil shale or oil shale for oil producers – oil shale, which is separated from limestone; mostly used in oil factories.

Economical year – in AS Eesti Põlevkivi economical year begins on 01 April and ends on 31 March.

Fuel oil shale – oil shale used in power plants as fuel for power production.

Lower heating value – or **net heating value** is obtained by subtracting the latent heat of vaporization of the water vapour formed by the combustion from the gross or higher heating value.

ROM – run-of-mine, the rock received from a mine before processing such as crushing or grinding.

Trade oil shale – oil shale used for final consumption.

Upper heating value – **or gross or high heating value** is the amount of heat produced by the complete combustion of a unit quantity of fuel.

List of publications

The doctoral thesis consists of a summary and the following papers:

PAPER 1 Tammeoja, T., Reinsalu, E.; 2008. Forecast of Estonian oil shale usage for power generation. Oil Shale, 2008, Vol 25 No 2 S, 115-124.

http://www.kirj.ee/public/oilshale_pdf/2008/issue_2S/oil-2008-2S-3.pdf

PAPER 2 Tammeoja, T.; Loko, M.; Valgma, I.; Karu, V.; Tohver, T. 2007. Oil shale reserves in Estonia. In: 4th International Symposium "Topical Problems in the Field of Electrical and Power Engineering": Doctoral School of Energy and Geotechnology: 4th International Symposium "Topical Problems in the Field of Electrical and Power Engineering", Kuressaare, Estonia, 15-.20.01.2007. (Eds.) Lahtmets, R. Tallinn: Tallinn University of Technology Faculty of Power Engineering, 2007, 94-95.

PAPER 3 Tammeoja T., 2003 Oil shale in power industry. Oil Shale. Vol 20, No 2. p. 135-142.

PAPER 4 Valgma, I., Tammeoja, T., Anepaio, A., Karu, V., Västrik, A. 2008. Underground mining challenges for Estonian oil deposit. Koloquium. Schacht, Strecke und Tunnel 2008. pp 161-172.

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1 STRUCTURE AND CURRENT STATE OF OIL SHALE INDUSTRY IN ESTONIA

1.1 Overview of oil shale in the Estonian power industry

The Estonian power industry is characterized by a great share of oil shale; it is the main source for power generation and has its part in heat energy. In 2005, the share of oil shale in power generation was over 90 percent. The total share of oil shale in power and heat energy generation was nearly three quarters (Figure 1.1-1).

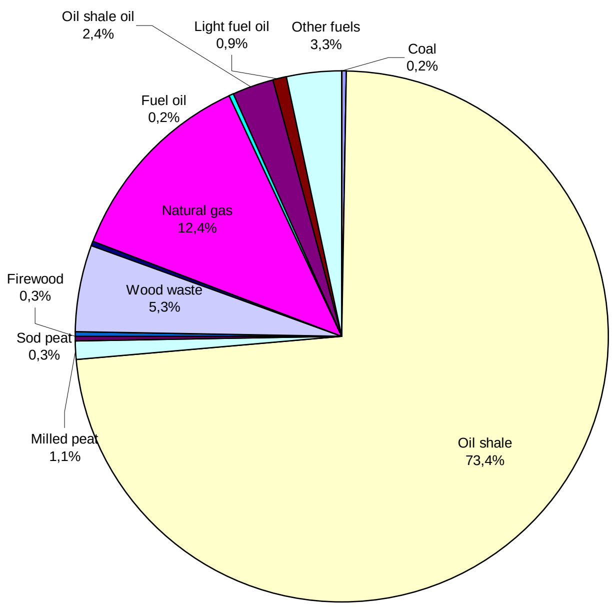

Figure 1.1-1 Fuels used for power and heat generation in Estonia in 2005

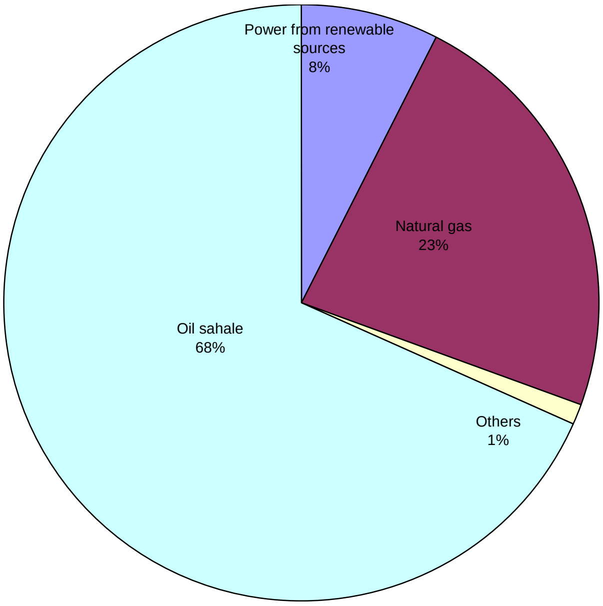

Figure 1.1-2 Predicted share of fuels for power generation in 2015

According to the government development plan setting out the use of oil shale until the year 2015, there are the following alternatives for the development of the Estonian power industry:

1. Continue renovation of Narva power plants, orientating on circulating fluidized bed technology.
2. Apply other technological solutions in the oil shale based power industry like combustion under pressure; blending oil shale with other (including renewable) fuels; large–scale production of shale oil and its use in local power generation.
3. Change radically the structure of the Estonian energy sector, abandoning oil shale and concentrating on other mainly imported energy sources. The most possible alternatives would be natural gas and coal.
4. Co-operation with other countries, e.g. participation in the nuclear power plant in Lithuania where the stuff and infrastructure already exist.

The present thesis is based on the assumption that Estonia will continue with remarkable share of oil shale based energy policy.

According to Directive 2003/54/EC of the European Parliament establishing common rules for the internal market in electricity, Estonia has to open 35 per cent of its electricity market by the year 2009 and fully by 2013. Thus, the Estonian oil shale based power industry faces a challenge to maintain its competitiveness in open market conditions.

The prognosis and scenarios of developments of Estonian power consumption made by Professor Enno Reinsalu from Tallinn University of Technology Department of Mining are discussed in PAPER 1. The postulates of the paper are:

- Economical and technological advancements can be forecasted up to 20 years
- Consumption of power depends on economic growth
- There is no option to get rid of oil shale in power production in the foreseeable future
- Growth of crude oil price is inevitably followed by increasing amounts of production of shale oil

Oil shale is not used only as a fuel for power plants, but also in the chemical industry, mainly for oil production. It has gained in importance as the price of crude oil is rising. If a few years ago the future of the oil shale chemistry was under question, then by the time being the great plans addressing the development of this branch of industry have become a reality.

1.2 Oil shale consumers

Traditionally, there are two main kinds of oil shale: fuel or energetic oil shale and oil or technological or concentrated oil shale. The first kind is traditionally fired in power plants for electricity and heat production. The second kind is used in oil production and chemical industry. This qualification is probably becoming out-of-date and sets limits on people's way of thinking. The quality requirements and amounts of trade oil shale are given in Table 1.3-2.

The greatest oil shale consumer is the state-owned company AS Narva Elektrijaamad (Narva Power Plants). This power generation complex consists of two power plants – Eesti Power Plant and Balti Power Plant.

The biggest chemistry factories are VKG Aidu Oil OÜ and Kiviõli Keemiatööstuse OÜ (The Kiviõli Oil Shale Processing Plant), and the oil factory of Eesti Power Plant. Smaller amounts of oil shale are used for cement production by AS Kunda Nordic Tsement.

Currently, the quality requirements for the oil shale used in power plants and for oil production are different. That concerns both the heating value and particle size. As an exception serves the oil factory of Eesti Power Plant where the same oil shale, which is used in the power plant is used also for oil production. This conception of trade oil shale classification will probably be changed in the near future due to the development of technology at power plants and in oil production.

Table 1.2-1 Oil shale consuming industry in 2007

		Eesti Power Plant	Balti Power Plant	VKG Aidu Oil OÜ	Kiviõli Keemia-tööstus OÜ	AS Kunda Nordic Tsement
Oil shale consumption	mill t	9.87	1.69	1.80		0.10
Field of use		power generating / oil producing	power generating	oil producing	oil producing	cement
Quality agreed in contract *	MJ/kg	8.4	8.4	11.32	11.32	11.60
Quality agreed, in upper heating value figures **		10.70	10.70	13.86	13.86	

* Contract states the lower heating value and moisture content limit

** calculated in moisture content of 12% for VKG Aidu Oil and Kiviõli Keemiatööstus and in moisture content of 10% for all other consumers

1.3 Oil shale mining industry

The biggest oil shale mining enterprise is AS Eesti Põlevkivi, whose shares belong 100 percent to the state-owned company Eesti Energia AS (Estonian Energy). The company owns two underground mines (Estonia and Viru), and two open casts (Narva and Aidu). There is also Kiviõli Keemiatööstus OÜ with its own open cast and AS Kunda-Nordic Tsement that mines part of needed oil shale in its own open cast and buys part of oil shale from AS Eesti Põlevkivi.

The Estonia and Viru mines and Aidu open cast have non-selective extraction of bed and quality management is mainly conducted in the concentrating plant, which allows them to produce both kinds of oil shale. Narva open cast works extract oil shale layers selectively with rippers and is introducing surface miners currently. It is situated near Narva Power Plant and is giving all the production there.

In past years, the high oil price has increased oil producers' interest in opening their own mines. A long-term Public Fuel and Energy Sector Development Plan until 2015 has been worked out [2]. On its basis the Development Plan of Power Industry was elaborated. At the current consumption level and technical-economical state of power plants, the proven oil shale reserves will last another 40 years. If the consumption remains the same, Eesti Põlevkivi has to open new mines in 15 years. If the consumption grows, new mines have to be opened earlier. Besides the reserves owned by Eesti Põlevkivi, there are some other companies possessing their own reserves:

- in 2003 Kiviõli Keemiatööstus OÜ opened its surface mine in the Põhja-Kiviõli mining field (reserves ~25 million tonnes);
- in 2004 VKG Aidu Oil OÜ received the permission for mining of oil shale in the Ojamaa mining field (reserves ~65 million tonnes)

- several companies have applied for a permit to conduct mining in the Uus-Kiviõli exploration field (reserves ~200 million tonnes)[1]

Potential new mines are handled in researches carried out in Tallinn University of Technology Department of Mining [3].
Production data of mines of AS Eesti Põlevkivi are given in Table 1.3-1.

Table 1.3-1 Production data of AS Eesti Põlevkivi mines in the 2006/07 economic year.

	Unit	Estonia mine	Viru mine	Aidu open cast	Narva open cast
Total trade oil shale, consists of.	10^6 t	4.71	1.91	1.93	4.73
	MJ/kg, lower	11.250	11.947	11.160	10.694
fuel oil shale	10^6 t	3.85	1.19	1.72	4.73
	MJ/kg, lower	10.696	10.780	10.816	10.694
concentrated oil shale	10^6 t	0.86	0.71	0.21	
	MJ/kg, lower	13.835	13.887	13.817	
Ron-of-mine	10^6 t	8.34	3.05	2.65	4.73
	%	56.5%	62.5%	72.7%	100.0%
Waste	10^6 t	3.63	1.14	0.72	0
	%	43.5%	37.5%	28.3%	0.00%
Design production*	10^6 t	5	2	2	5

* designed production is annual possible amount of trade oil shale according to initial project concerning 60 per cent oil shale and 40 per cent waste.

Table 1.3-2 Transportation distances between mines and consumers via railway

	Estonia mine	Viru mine	Aidu open cast	Narva open cast *
Eesti Power Plant	46	38	--	3 19
Balti Power Plant	--	--	67	--
VKG Aidu Oil	36	17	17	--
Kunda-Nordic Tsement	--	--	62	--

* There are two different loading points in Narva for different districts of mine

[1] there are more applications submitted on different exploration fields today

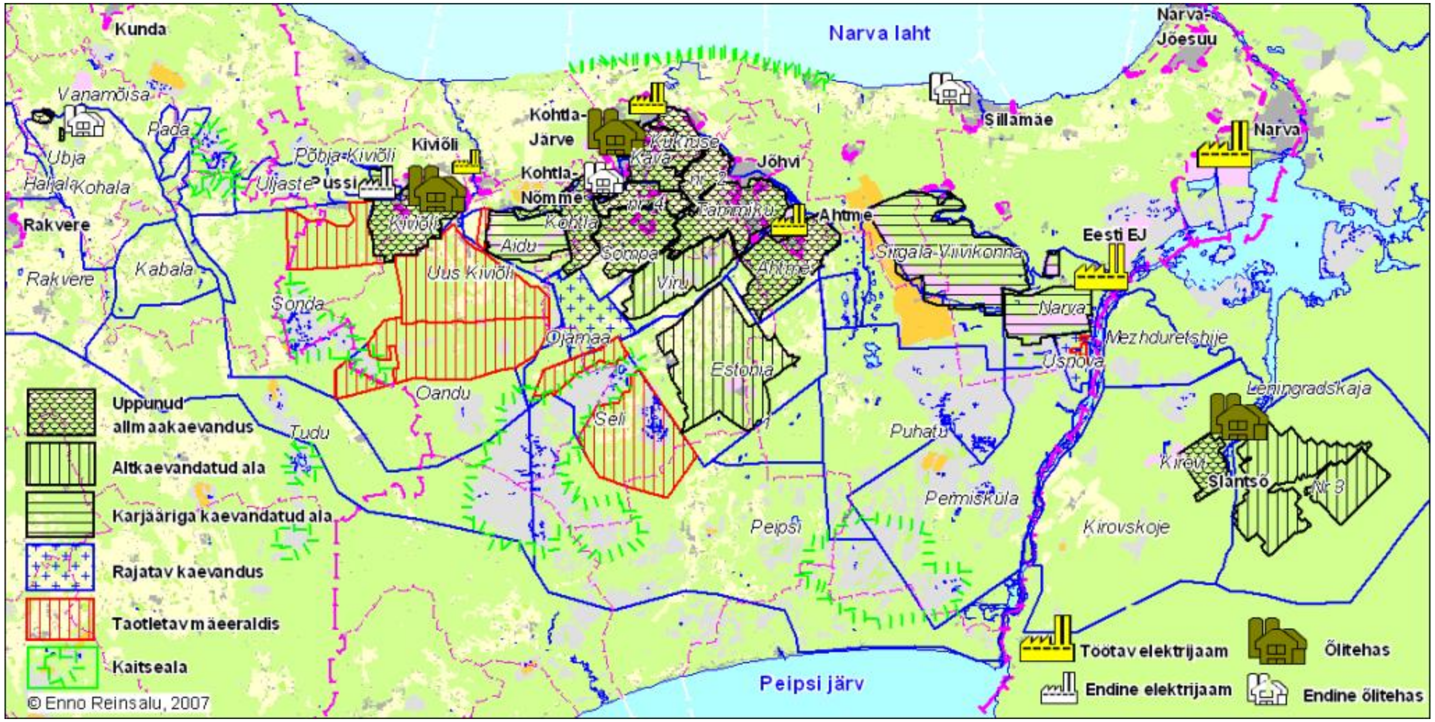

Figure 1.3-1 Baltic Oil Shale Basin: Estonia and Leningrad deposits. Exploration blocks and mine fields [21]

1.3.1 Production capacities of mines

Production capacities of the currently operating mines are limited and reaching their maximums. In underground mines the limiting neck is a concentrating plant. Total limit run-of-mine is around 10 million tonnes for Estonia mine and 3.5 million tonnes for Viru mine. Open cast production is limited by overburden removal excavators. Their current work is economically feasible because they are old and depreciation is not paid. Buying of new ones would be too expensive. Current conditions allow to produce 4 million tonnes of run-of-mine from Aidu open cast and 5.5-6 million tonnes from Narva open cast.

2 OPTIMIZATION OF OIL SHALE INDUSTRY

2.1 Overview of previous studies

Optimization of oil shale industry is a continuing process and has been handled by different scientists over years.

The first studies were conducted in the 1970s in the Estonian Academy of Sciences Department of Economics by Professor Ilya Kaganovich (supervisor), PhD Anton Laur, PhD Koidu Tenno, PhD Ninel Barabaner. Prof Kaganovich worked out the basics of the theory of economical-mathematical optimization [24] where examples from oil shale industry were applied. After the first oil crisis in the seventies of the last century, Professor Kaganovich questioned the construction of TSK-factory near Narva Power Plants referring to the drop in oil prices and high capital investments. The scientists of the Estonian Academy of Sciences focused mainly on shale oil production and optimization of its quality. PhD Ninel Barabaner concentrated on optimization of oil shale heating value [1].

A more detailed optimization research was conducted in the Estonian Branch of Skotchinsky Institute of Mining Engineering under supervision of PhD Enno Reinsalu. The results obtained served as basis for drawing up the state development plans of oil shale utilization. In her PhD thesis study (supervisor PhD Enno Reinsalu), Galina Tishkina created a technological scheme for three new oil shale mines (Kuremäe, Permisküla and Uus-Kiviõli), 5 Mt oil shale each. This scheme, which can be called "a great development plan for the oil shale industry", did not realize because it assumed too high capital expenditures.

A conflict rose between the economic calculations and official Soviet development plans. Like Kaganovich's group, those researches also showed that there were not enough economical and natural resources for such huge plans [22]. For Enno Reinsalu, the conflict resulted in declining his application for the Doctor of Economics degree in Moscow.

PhD Anton Laur and PhD Koidu Tenno from the Estonian Academy of Sciences studied the marginal cost of oil shale power industry in Estonia. Their methodology included mainly analysis and modelling of general statistical data [25], while the mining technology and oil shale enrichment very dealt with superficially.

The oil shale power industry and its future developments have been dealt with by Academician Arvo Ots, Professor Olev Liik and others. Optimization of the mining structure has been continued by Enno Reinsalu in Tallinn University of Technology Department of Mining. The author of the current thesis took part in these studies. An economic model with all oil shale mines was used [23]. However, the model was too simplified and did not sufficiently consider the mining and economical conditions.

2.2 Task

2.2.1 Goal

The goal of the present study is to give a tool for solving problems related to the oil shale mining and processing industry. This includes elaboration of a mathematical model considering all the aspects of oil shale mining, from geological to economical, in one sequence to optimize the whole sequence.

The study includes finding solutions in material handling (concentrating of oil shale) to estimate their effectiveness. The following factors are considered in the model:

- geological conditions in oil shale quality forming and management of mining works vary with mines;
- mining technology depends on the quality requirements of the commodity;
- preliminary material handling is made for quality management;
- delivery and logistics have to be optimal;
- to assure quality, a new price policy has to be introduced;
- it is the energy contained in oil shale that costs and pays, not the mass of rock.

2.2.2 Feasibility studies in the mining industry

The mineability of deposit is evaluated by feasibility studies [9]. The conditions of Estonian oil shale deposit are quite simple and well-known and therefore using of analogy method is quite effective here. So, the study contains a working model of an oil shale mine or an open pit. The model is described in more detail in chapter 3.

In every feasibility study the mining conditions are analysed not only on the timescale but also considering different economical conditions (labour, energy, material prices, also changes in the price of the commodity itself). This is not discussed in a particular detail in the current paper but the model allows us to do this in a relatively short notice.

The current paper is not a feasibility study. Its build-up differs from a traditional feasibility study because such indicators as payback time, IRR, NPV, sensitivity analysis, risk analysis are not included although these principles are taken in basis. The goal is rather to give an initial impact of developing such a way of thinking in the oil shale mining industry.

The most important thing is to change the current way of thinking, which handles oil shale as a mass of rock not an energy source. This has resulted in the current price policy, which does not apply different price for oil shale of higher heating value for power plants. There is a minimum heating value set in the contract and a fixed price for a tonne of oil shale. This does not make mines interested in developing enrichment technologies.

It is just becoming an issue that oil shale mining and further processing in a power plant or oil factory is in same sequence and optimal heating value may differ from current values. Issues are becoming more topical with raising environmental taxes.

Higher heating value also results in reduced emissions of CO_2 and ash. However, this is not the subject of the present study, but an issue for thermal and chemistry engineers and scientists. Fitting current study of miner's side and final processing together gives answers about feasibility and optimization of oil shale industry.
As previous researches by I. Kaganovitch, N. Barabaner, E. Reinsalu and G. Tishkina have shown, the system of oil shale industry is very complicated [1, 7, 8, 9, 11, 15, 24]. This is due to the circumstance that the object is very miscellaneous and the system is also quickly developing and changing.

- There is still old-fashioned command economy and cost-based approach in economical evaluation prevailing in the state owned companies as Eesti Põlevkivi and Eesti Energia. The actual influences of different decisions on profitability are not counted. Decisions are made too locally and do not evaluate the whole system from winning to final utilization.
- Modern computing technology allows to calculate and take into account several factors tied in one sequence. That means the use of mathematical economical-technical models and data collection. Most local technological changes exert influence on the other parts of the process. Therefore, it is useful to apply such models in the decision-making process.

2.2.3 Geological conditions

The oil shale bed in Estonia has a thickness of 0…100 m and is located at a depth of 1.4…3.2 m in an area of 2489 km^2 (Figure 3.1-1). The mineable seam consists of seven kukersite layers and four to six limestone interlayers. The oil shale layers are indexed from A up to F1. The energy rating of the bed is 15…45 GJ/m^2.
To date, a bit more than half of oil shale is mined in open casts. 30 m is the limiting depth for draglines with 90-m-long booms. Room-and-pillar mining is the only underground oil shale mining method today. In 2001 the last longwall mine was shut down.
The feasibility of the oil shale mining depends on energy rating, calorific value of the layers, thickness and depth of the seam, location, available mining technology, world price of competitive fuel and its transporting cost, oil shale mining and transporting cost. In addition, nature protection areas are limiting factors for mining.
The economic criterion for determining Estonia's kukersite oil shale reserve for electricity generation is the energy rating of the seam in GJ/m^2. It is calculated as the sum of the products of thickness, calorific values and densities of all oil shale layers A-F1 and limestone interlayers. A reserve is mineable when energy rating of the block is at least 35 GJ/m^2 and subeconomic if energy rating is 25…35 GJ/m^2. According to the Balance of Estonian Natural Resources, the oil shale reserve was 5 billion tonnes in the year 2000. Economic (mineable, active ≅ *aktiivne* in Estonian) reserve was 1.5 billion t and subeconomic (passive ≅ *passiivne*) 3.5 billion t. These figures apply to oil shale usage for electricity generation in power plants. In the case of large-scale use of oil shale for cement or oil production, the criteria

must be changed. Therefore, in changing economical conditions it is important to know operating expenditures and possible revenues.

2.2.4 Limitations

Because of different limitations mining is not possible in all parts of the deposit. This concerns mainly the areas of nature conservation or under settlements and various constructions. In different districts different mining methods are also possible.

3 MODELLING

3.1 Mathematical model of oil shale mining

There is a mathematical model in spreadsheet consisting of several sub-tables:

- Economical data;
- Mining conditions;
- Environmental taxes;
- Selling quantities in mass and energy units;
- Heating values of trade oil shale;
- Transportation distances;
- Transportation costs;
- Mining and transportation expenditures.

The main variable input data for using a model and calculating variants for different conditions are the desired heating value and quantity of trade oil shale from each mine. For future prognosis mining conditions and cost changes have to be inserted. Mining conditions have to be found in aid of GIS programs and entered manually. The model gives required ROM, mined area and mining expenditures. The main principles and correlations in the model are given in chapter 3.2.1.

The model helps to:

- prognose future mining expenditures providing that prices, environmental taxes, labour costs, materials and also mining conditions change in future;
- calculate mining expenditures depending on the quality of trade oil shale;
- if comparing this to respective data from power or oil production, the whole chain of the industry can be optimized;
- use the analogy method to forecast mining feasibility in other exploration fields.

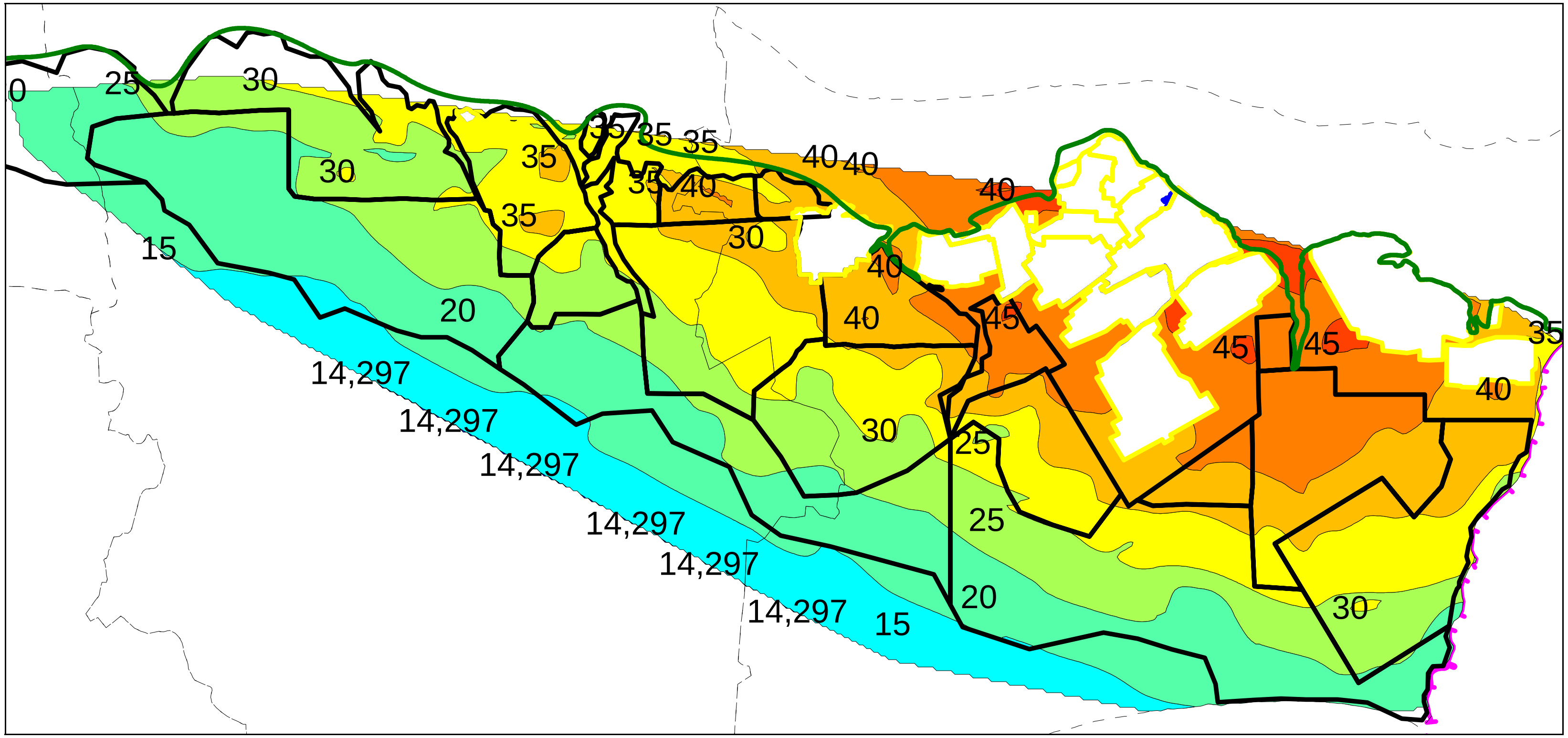

Figure 3.1-1 Energy rating of oil shale bed, GJ/m². By Ingo Valgma.

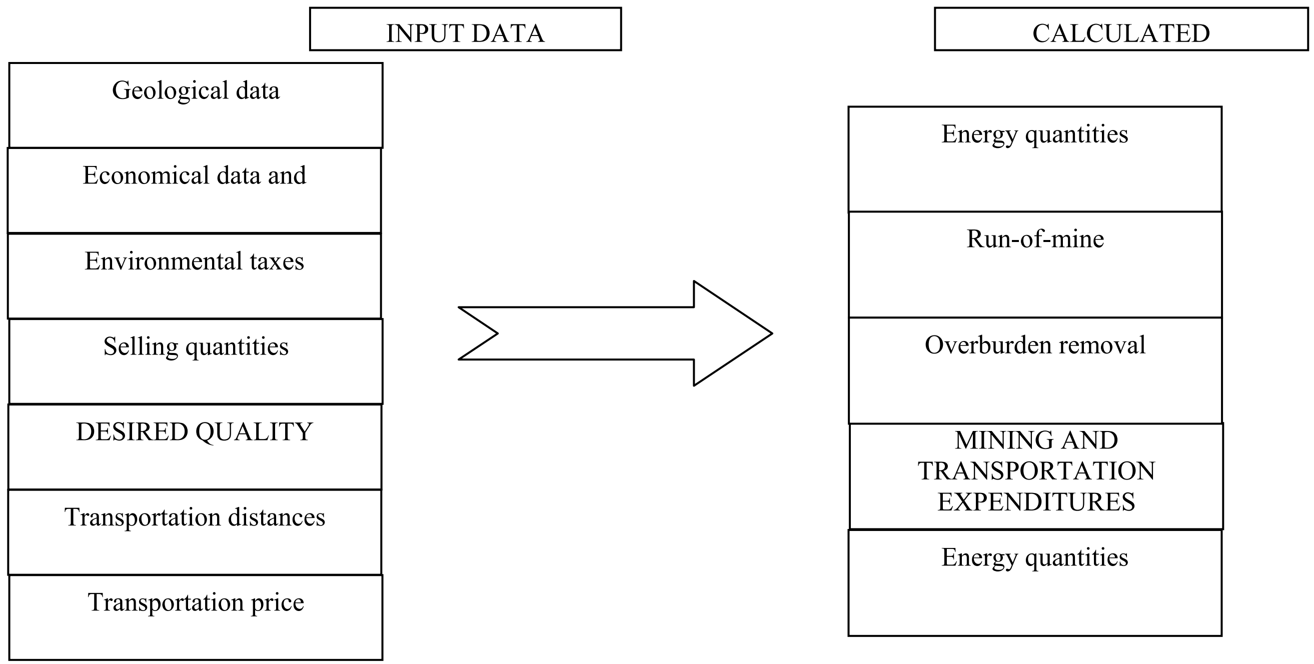

Figure 3.1-2 Principle of Economic Model of Oil Shale Flows and Cost

3.2 Methodology

Economical and mining data were taken from the report of Eesti Põlevkivi. The data is analyzed to create relations between mining conditions and economical data and are put into a spreadsheet, making a mathematical model. The main goal of the model is to give mining expenditures by varying geological data and required quantities and qualities of trade oil shale.

3.2.1 Analysis of mining expenditures

The aim of analysis of mining expenditures is to create a basis for a mathematical economic model of mining enterprise to allow making of prognosis of mine's economical state in altering mining and economical conditions. For example, what are the mining costs in different districts of the oil shale seam heating value or if the consumers require trade oil shale of different heating value. Presumption for that is to make economical correlations between quantities and costs. Costs are divided into fixed and variable costs.

Fixed costs are given in Table 3.2-1 Fixed costs Depreciation from economical report is 100 percent set under fixed costs. This is a traditional approach although can be argued as it depends on the equipment bought and the amount of equipment depends on production if not to consider seasonable fluctuations.

Table 3.2-1 Fixed costs

Depreciation
Overheads (office, IT ect)
Expenditures on buildings and constructions
Salary of administration and office labour
Electricity for water removal

Fixed costs are set on the basis of their formation. Most of expenditures in financial reports are given in Estonian crowns per ton of oil shale sold. That does not give adequate information about how the expenditures may change in changing mining and economical conditions. It is quite simple to evaluate the influence of change of price in salaries, energy and materials cost if knowing the share of these items in total operating expenditures. If cost price of oil shale is 9 EUR/t and the share of labour costs is 40 per cent, then a 20% per cent increase in labour costs results in oil shale price of $9 \times (1 + 0.4 \times 0.2) = 9.72$ EUR per ton. But it is much more difficult to determine the influence of seam quality on cost price or if different factors change simultaneously.

Table 3.2-2 Fixed costs and their dependence on mining conditions.

Direct mining operations		
Roof bolting	Area of caves	EEK/m^2 (area of caves)
Explosives and blasting supplies	Open case mining and water trench	EEK/m^3(ROM)
Underground mining		
Drilling tools	Production and water trench	EEK/m^3(ROM)
Other materials (timber and others)		EEK/m^3
Electricity	Price	EEK/kWh
	Mining	EEK/m^3
	Ventilation	EEK/m^3
	Other consumption	EEK/m^3
Salary of mining workers	Excluding concentration and overburden	EEK/m^3(ROM)
Expenditures on working tools	Materials, spare parts, maintenance, others	EEK/m^3(ROM)
	fuel	EEK/m^3(ROM)
Mine transportation		
Electricity	Underground transportation	EEK/m^3(ROM)×km
Expenditures on transportation equipment	Materials, spare parts, maintenance, others	EEK/m^3(ROM)×km
	Fuel	EEK/m^3(ROM)×km
Overburden removal		
Electricity	Overburden removal	EEK/m^3(overburden)
	Drilling equipment	EEK/m^3 (hard overburden)
Materials	Explosives	EEK/m^3 (hard overburden)
	Excavators	EEK/m^3 (hard overburden)
	Drilling equipment	EEK/m^3 (hard overburden)
Labour	Blasting	EEK/m^3 (hard overburden))
	Drilling	EEK/m^3 (hard overburden)
	Excavators	EEK/m^3 (overburden)

Table 3.2-2 Fixed costs and their dependence on mining conditions. (continued)

Crushing and concentration plant		
Electricity		kWh/m³(ROM)
		EEK/m^3 (ROM)
Magnetite		EEK/m^3 (ROM)
Materials		EEK/m^3 (ROM)
Labour		EEK/m^3 (ROM)
Others		EEK/m^3 (ROM)

Table 3.2-3 Mining conditions

Geological mass production of oil shale layers from layers A to F1*		t/m^2
Average heating value of mined seam *		GJ/t
Thickness of mined seam *		m
Hard overburden *		m
		thous m^3
Soft overburden*		m
		thous m^3
Average transportation distance in mine*		km
Required area	caved area	thous m^2
	caved area and pillars	thous m^2
Volume of ROM		thous m^3
Volume of residues		thous t
Volume of water removed*		thous m^3
Losses in pillars*		%
Production losses*		%
Heating value of residues*		MJ/kg

* input data (data without * are calculated by a model)

3.2.2 Dependence between heating value and mining expenditures

As mentioned above, higher heating value of trade oil shale calls for higher cost price of oil shale. The following figures indicate those correlations. As the aim of the current study is not to provide ready answers but construct a working model, the example is given on the basis of one working mine.

Some figures given here show the dependence between operating and transportation expenditures and upper heating value of trade oil shale (Figure 3.2-1); the dependence between energy cost and upper heating value of trade oil shale; the dependence between the cost of one ton of oil shale and upper heating value of trade oil shale in Viru mine. To make calculations comparable, the amount of energy is taken to remain the same in each heating value. The transportation from the mine's loading point to the customer is considered under transportation on the graphs. The calculations given here do not consider the investments on new concentrating plant for fine oil shale.

The fact that the quality and cost of trade oil shale do not change proportionally and the cost/quality elasticity can be seen in Figure 3.2-4.

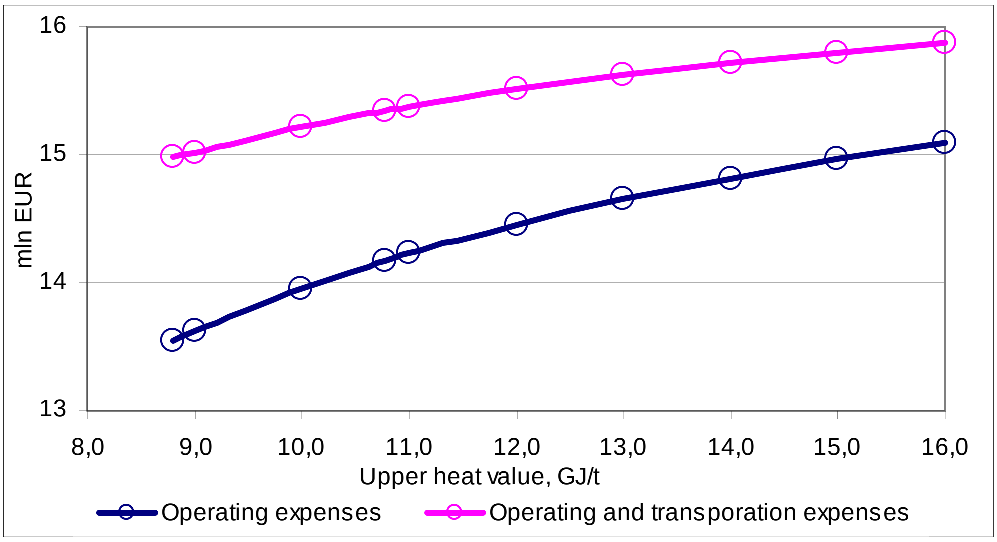

Figure 3.2-1 Dependence between operating expenditures and upper heating value of trade oil shale in case of Viru mine. Energy amount remains constant.

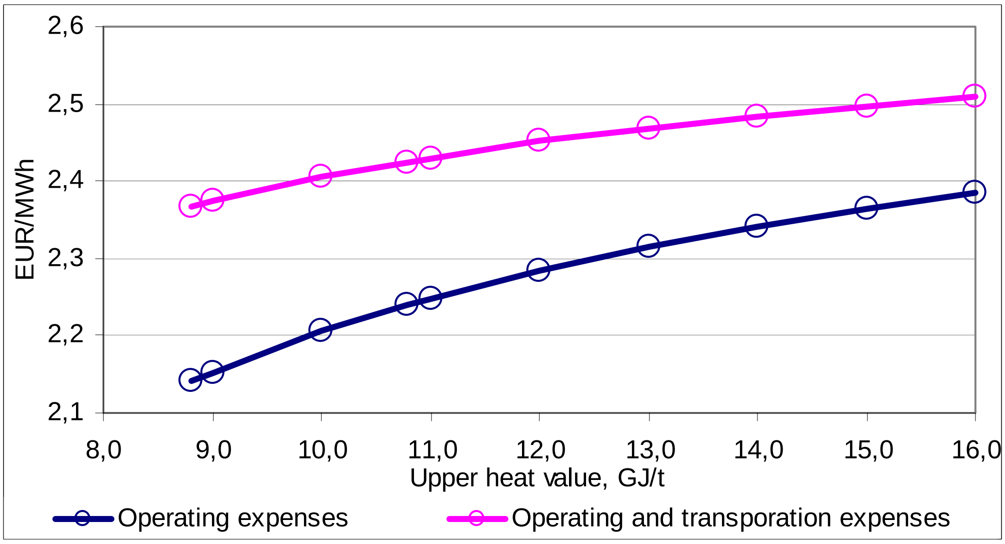

Figure 3.2-2 Dependence between energy cost and upper heating value of trade oil shale in case of Viru mine. Energy amount remains constant.

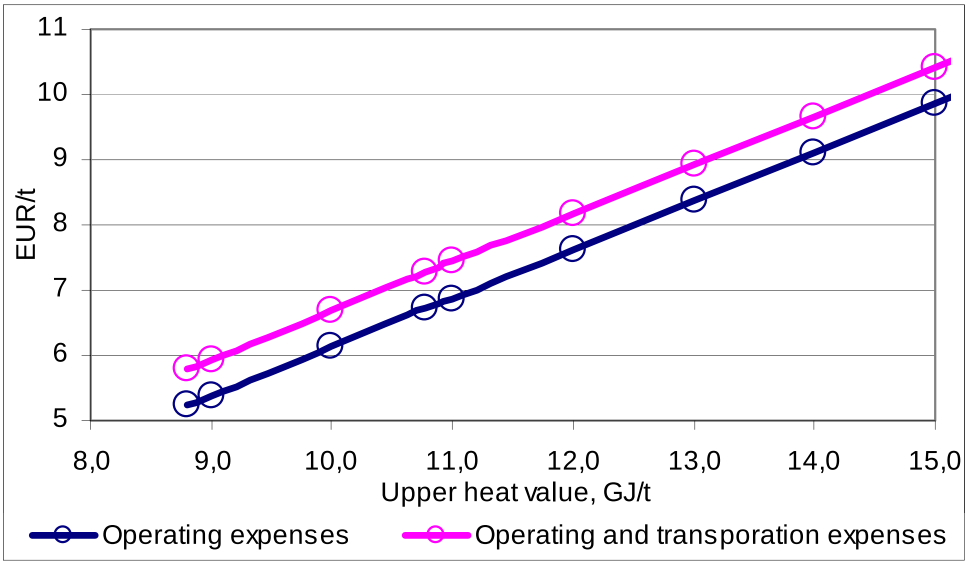

Figure 3.2-3 Dependence between the cost of one ton of oil shale and upper heating value of trade oil shale in case of Viru mine. Energy amount remains constant.

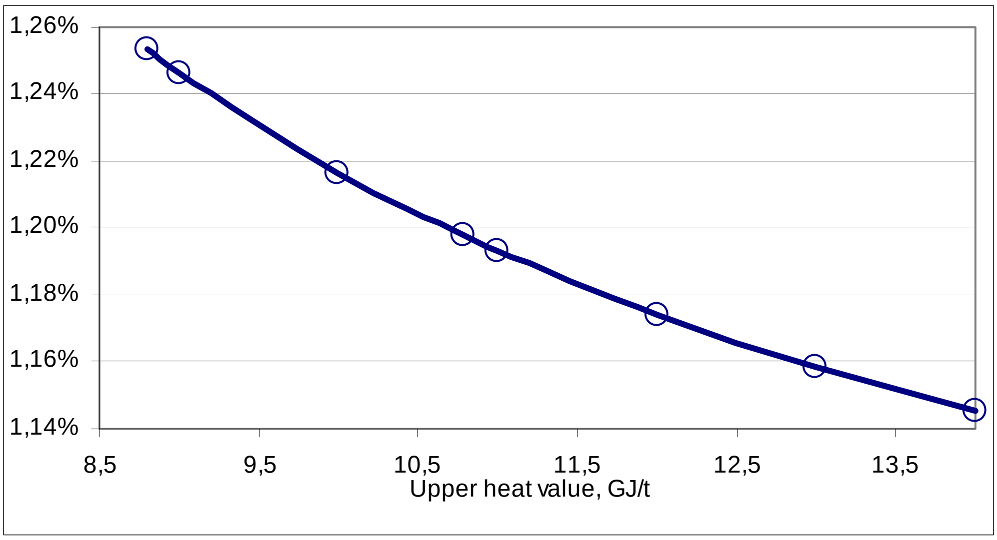

Figure 3.2-4 Dependence between the cost of one ton of oil shale and upper heating value of trade oil shale in case of Viru mine. Energy amount remains constant

According to the study ordered by Eesti Energia, there were two options of different heating value calculated as 10.5 and 11.5 MJ/kg. The price of oil shale of those variants was calculated including investments on new concentrating equipment. The results obtained for Estonia mine are given in Table 3.2-4.

Most economical data is based on the 2006/07 economic year; salary is the Estonia's average; environmental taxes date from the year 2008. A prognosis of costs for the year 2020 is also given. As different costs in Estonia are still changing at a different rate, the growth is taken different in this case. Labour cost remains one of the fastest growing costs in the nearest years to come and is estimated at 7 percent, other costs at 5 percent.

As already mentioned, the model is purely mathematical and does not make any thinking for an engineer. The first column indicates the base case, i.e. the current state. The second column indicates the case where average lower heating value of trade oil shale is 11.5 MJ/kg. In this case, oil shale of particle size <1 mm is considered as waste because it is not known how to dry this material. Very fine oil shale is extremely sticky if got wet and it might be quite a challenge to dry it. The proportion of such a material can be estimated at 12 percent. The third column indicates the case when <1 mm material could be dried to sufficient level and added to the main product. The average heating value of 10.64 MJ/kg would be obtained. Costs from 8.87 to higher calorific value jump rapidly as it is required to construct a new concentrating plant to separate very fine oil shale and limestone.

Table 3.2-4 Example of MinEx calculated. Estonia mine.

		Current costs			Costs in 2020		
Total trade oil shale	thous t	5 951	3 530	4 710	5 951	3 530	4 710
Average heating value of trade oil shale	MJ/kg	**8.87**	**11.50**	**10.64**	**8.87**	**11.50**	**10.64**
Total MinEx	EUR/t	8.88	17.36	12.85	17.4	33.6	24.9
Total MinEx	EUR/GJ	0.81	1.23	0.98	1.58	2.39	1.89

4 TECHNOLOGICAL OPTIONS OF OIL SHALE PROCESSING

In case of non-selective mining oil shale has to be processed in a concentration plant to achieve the desired quality for customers. Oil shale is concentrated in heavy media separation drums. But currently not the whole ROM is concentrated. The rough balance of oil shale is 40 percent of fine unconcentrated oil shale directly sold to power plants; 20 percent of concentrate or coarse oil shale concentrated in heavy media drums and 40 percent of waste rock consisting of limestone. The energy share allows mines to achieve the required lower heating value of 8.4 MJ/kg by screening it through 25-40 mm screens. The share of such a material is nearly 40 percent depending on location. As it contains significant amount of limestone, which increases emissions of ash, CO_2 and other undesired and ecologically harmful residues, recently searches for concentrating this part of production were begun. There are a couple of options for that purpose including selective crushing of oil shale aimed at separating rock pieces consisting half of limestone and half of oil shale. But more important options are based on gravity separation either in liquid or air flow cyclones. Methods are widely used in processing of different minerals. What makes it challenging in oil shale is the fact that oil shale is a clayish material and floating of very fine oil shale in water gives us sticky mud.

5 DISCUSSION

Several problems have been discussed among representatives of the industry and other persons familiar with the subject. One of those concerns the cost of oil shale of different quality? The complexity of the system was discussed above.

Here is a simple example showing how much money a mine will loose if the oil shale sold is of higher calorific value than stated in the contract. Simplified approach is to calculate the per cent difference of heating values and reduce the profit by the same percentage. In reality, fixed and variable costs must be taken into account and also the fact that if the client (power plant in our case) gets more energy from an oil shale tonne, he requires less oil shale and reduces the order by a respective amount or even a bit bigger amount of oil shale due to increased efficiency. The calculation results are given in 5–1.

The mining enterprise has to sell 1 194 thousand tonnes of fuel oil shale with lower heating value of 8.4 GJ/t and 712 thousand tonnes of concentrate. How much money will the mine loose if the average heating value of the sold fuel oil shale is 8.6 MJ/kg?

The first column indicates a base case when all quality requirements are exactly satisfied.

The second column shows the case of calculation. It is provided that the moisture content of trade oil-shale is 12 percent. Mining expenditures are 171 thousand euros higher in that case, while income remains the same. But there is something which has to be seen. If a power plant gets oil shale of higher heating value then efficiency and, thus, the amount of energy theoretically increases. And if that amount cannot be sold, the power plant will buy less tonnes of trade oil shale.

Number 3 column shows what happens to income and expenditures if the power plant buys the same amount of energy. Expenditures are 35 thousand euros higher and income decreases 206 thousand euros. The actual total loss is 241 thousand euros.

The mining enterprise has to sell 1 194 thousand tonnes of fuel oil shale with lower heating value of 8.4 GJ/t and 712 thousand tonnes of concentrate. How much money will the mine loose if the average heating value of sold fuel oil shale is 8.6 MJ/kg[2]?

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[2] balance calculated through lower heating values does not fit as it depends on moisture content; moisture content in trade oil shale is not only geological but also depends on other factors as rain, therefore upper heating values are taken providing 12 percent of moisture content.

Table 5-1 Loss of money by selling oil shale of higher quality than stated in the contract.

	1.	2.	3.	
Lower heating value according to contract	8.4	8.6	8.6	GJ/t
Amount of fuel oil shale sold	1 193 704	1 193 704	1 167 359	t
Amount of concentrated oil shale	712 406	712 406	712 406	
Upper calorific value of fuel oil shale	10.702	10.944	10.944	GJ/t
Lower calorific value of fuel oil shale	8.4	8.6	8.6	GJ/t
Moisture content of fuel oil shale	12	12	12	%
Upper calorific value of fuel oil shale	13.887	13.887	13.887	GJ/t
Amount of energy in fuel oil shale	12.8	13.1	12.8	PJ
Amount of energy in concentrated oil shale	9.9	9.9	9.9	PJ
Cost price of trade oil shale	7.55	7.64	7.67	EUR/t
OpEx	14 396	14 568	14 431	thous EUR
Increase of OpEx		171	35	thous EUR
Less income from sale (hind 7,81 EUR/t)			206	thous EUR
Total less income			241	thous EUR

6 CONCLUSIONS AND RECOMMENDATIONS

To date, the power generation in Estonia is based on oil shale. The share of oil shale in power generation is over 90 per cent. According to the prognosis of Estonian economic growth, the need for energy will grow and even if applying alternative power sources, it is not realistic that it could be reduced to less than 50 per cent of today's volumes in 2020. Because of the increasing cost of crude oil, oil generation from shale is of growing importance. But oil shale is very rich in ash, which results in huge amounts of solid residues. Besides, Estonian oil shale has a high content of carbonate minerals thus combusting and oil processing is accompanied by abnormally high emissions of CO_2. Although emission of sulphur dioxide is low due to carbonate minerals, limitation of SO_2 pollution is expected in the near future. In relation to growing environmental requirements, the interest towards utilisation of oil shale of higher calorific value has grown. As it is clear that higher calorific value of product causes higher production expenditures, the question arises where the optimal point is. Consumers are interested in a fuel raw material of higher quality. Upgrading oil shale results in higher operating expenses and requires also applying a new price scale. Optimizing the grade of the oil shale as well as the quality of the shale oil to best fit the interests of the mines and consumers is the subject of this paper. The current study considers only the cost side of the system, as the price side has to be decided by producers. It can be easily added to the model.

1. An economic model of trade oil shale flow and cost for mining industry has been worked out.
2. The model has been used in the study ordered by the state owned company Eesti Energia and its daughter company Eesti Põlevkivi.
3. The mathematical model of oil shale energy flow allows us to evaluate the operating expenses and the increase of sale price accompanied by an increase of oil shale quality.
4. Optimization of oil shale energy flows and rising of heat value require also application of a new price scale.
5. Calculations show that the quality and cost price of trade oil shale do not grow proportionally – in current state of quality 1 percent growth in quality results in 1.2 percent growth of trade oil shale cost price.

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9 KOKKUVÕTE

Töö sisuks on luua kogu süsteemi hõlmav ning erinevaid seoseid arvestav mudel põlevkivienergeetika ja -keemia erinevate tulevikustsenaariumite kiireks ja mitmekülgseks arvutamiseks ja põlevkivi kaevandamisel kerkivate küsimuste lahenduste leidmiseks ja töötlemiseks lähtudes järgmistest seisukohtadest:

- geoloogilised eeldused kauba kvaliteedi moodustumisel ja mäetööde juhtimine neid arvestades;
- kaevise väljamine ja töötlemine kauba kvaliteedinõudeid silmas pidavalt;
- kauba jaotamise optimeerimine;
- kauba kvaliteeti arvestav hinnapoliitika kvaliteedi tagamiseks.

On üldtuntud fakt, et põlevkivi kütteväärtus lõuna suunas, st mäetööde arenedes halveneb. Siiski on täpselt teadmata, millist kaubapõlevkivi me saame 5; 10; 15; 20 … aasta pärast.

Käesolev mudel aitab paraku veel leida vastuseid ainult põlevkivi kaevandamisel ja jaotamisel, kuid mudeli lõppeesmärk peaks olema käsitleda kogu ahelat kliendi juures lõpptöötlemiseni välja. Näiteks seoses uue tehnoloogia kasutuselevõtuga Narva Elektrijaamades, ei ole põhjalikult läbi töötatud kogu kaevise ja kauba töötlemise tsüklit põlevkivi katlasse andmiseni, sellest lähtuvat põlevkivi kvaliteediomaduste muutumist teiste tarbijate jaoks. See aga eeldab vastava ala spetsialistidega täiendava koostöö tegemist.

Eesti põlevkivitööstuses on visa muutuma on plaanimajanduslik ja kulupõhine lähenemine põlevkivikaevandamise majanduslikul hindamisel. Ühekülgne on erinevate otsuste ja tegevuste tegelik mõju kasumile, lähtutakse liigselt lokaalsetest optimumidest, arvestamata süsteemi terviklikkust. Loodud mudel võimaldab seda olukorda leevendada.

Mudeli loomise mahukamaid osasid oli AS Eesti Põlevkivi majandusnäitajate analüüs, mäetehniliste ja majanduslike näitajate omavaheliste seoste leidmine ning matemaatiline esitamine.

Mudeli esimeseks suuremaks praktiliseks väljundiks on selle rakendamine AS Eesti Energia tellitud töö ”Kasutustehnoloogiale vastava optimaalse koostisega põlevkivi tootmise tehnoloogilised võimalused ning majandusliku otstarbekuse analüüs” täitmine. Nimetatud uuring ning selle järeldused pole käesoleva doktoritöö kaitsmise hetkeks veel lõpetatud.

10 ABSTRACT

The purpose of the study was to create a model to handle the whole system and different ties of oil shale power and chemical industry for quick estimating and calculation of different future scenarios and solving the questions arising in oil shale mining from the following factors:

- geological conditions in quality forming and management of mining works in different mines are different;
- winning and processing of ROM taking quality requirements into consideration;
- optimization of oil shale delivery and logistics;
- applying adequate price policy to motivate continuing development.

It is a well-known fact that oil shale quality decreases towards south. It means that operating and also abandoned mines are located in the northern part of the deposit and the mining conditions generally become more and more unfavourable southwards. It is still unknown what kind of oil shale will be mind and how economical it will be in 5; 10; 15; 20... years.

A disadvantage of the model is that it helps us to find answers only to problems concerning the mining and delivery of oil shale. The end goal should be handling the process till the end products – power or oil. For example, a new power generating technology was introduced in Narva Power Plants, but the whole chain from winning, concentrating and burning the fuel has not been fully optimized. As today fuel and concentrated oil shale are strictly separated and sold to different consumers the change in trade oil shale quality exerts influence on other customers. To develop the model in this direction, additional co-operation with specialists working in the respective field is required.

The command economical and cost-based approach of oil shale mining estimation is hardly changing. Decision making is still one-sided and takes too much into account local optimums without seeing the system as a whole. The created model is a tool for solving the situation.

One of the bulkiest parts of the study was the analysis of economical and mining conditions, finding dependences between them and adding them into the mathematical model.

The biggest practical output of the model was its application in the study ordered by Eesti Energia (Estonian Energy Company) *Analysis of Oil Shale Flow in Accordance with the Energy and Oil Production*. The mentioned study was not completed and its final conclusions were not drawn by the time of defending the current thesis.

11 CURRICULUM VITAE

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3. Education

Educational institution	Graduation date	Education (field of study/degree)
Tallinn University of Technology Department of Mining	2002	Mining engineering/ MSc
Tallinn University of Technology Department of Mining	2000	Mining engineering/ BSc
Kiviõli Secondary School No.1	1996	Secondary education

4. Language competence/skills (fluent; average, basic skills)

Language	Level
Estonian	Fluent
Russian	Average
English	Average

5. Special Courses

Period	Educational or other organisation
September 2004 till May 2005	European Mining Course
January 2002	Intensive course of English. Language Learning Service
November/December 2001.	Fast reading. Kiirlugemiskool OÜ (Fast Reading School)
September to November 2001	Course of English. OÜ Sugesto

6. Professional Employment

Period	Organisation	Position
	VKG Kaevandused OÜ	Mine engineer
11 November 2007 – 21 April 2008	Tallinn University of Technology, Department of Mining	Extraordinary researcher
09 October 2006 – 09 November 2007	AS Saku Metall	Project manager
01 June 2005 – 06 October 2006	AS Eesti Põlevkivi	Mine designer
25 February 2002 – 09 September 2004	AS Eesti Põlevkivi	Quality specialist
01 September 2001 – 22 February 2002	Tallinn Technical University	Researcher

16 March – 31 August 2001 Joint Company foreman	AS Aidu Karjäär (Aidu Open Cast)	Foreman
13 July – 31 August 2000	AS Estonia Kaevandus (Estonia Mine)	Electrician
2 July – 13 August 1999	AS Estonia Kaevandus (Estonia Mine)	Electrician trainee
8 July – 15 August 1998	AS Viru Kaevandus (Viru Mine)	Blaster trainee
June, July 1995; July, August 1994	Saw-frame works of Lüganuse	Loader

7. Scientific work

Mining technology, mineral economics.

8 Defended theses

Tauno Tammeoja, Master's Degree, 2003, (sup) Enno Reinsalu, Optimization of Oil Shale Mining Flow; /Eesti Põlevkivi reorganiseerimiskava ja majandusmatemaatiline mudel/, Department of Mining, Faculty of Power Engineering, Tallinn University of Technology (in Estonian).

9. Main areas of scientific work /Current research topics

Oil shale quality, oil shale mining optimization

10. Other research projects

Subject	Nr of Project	Financing source	Duration
Usage of Mined Out Areas	ETF5913	ETF	01.01.04–31.12.06
Analysis of Oil Shale Flow in Accordance to the Energy and Oil Production	Lep7038AK	Contract	15.05.07–30.09.08
Creating Environment for Sustainable and Acceptable Mining	SF0140093s08	SF	01.01.08–31.12.13
Conditions of Sustainable Mining	ETF7499	ETF	01.01.08–31.12.11

Appendixes

Appendix 1
Mathematical model

2004/05 majandusnäitajate kogum laest võetud või mitte päris usaldatavad andmed

LÄHTEANDMETE TÖÖTLUS, s.t. MAJANDUSLIKUD ALGANDMED

Ühik EEK tähendab aastast kulu			Estonia	Viru	Aidu	Narva
			Kamber, rikastamine	Kamber, rikastamine	Lausväljamine, rikastamine	Selektiivne
PÜSIKULUD						
Kulum		EEK	78 448 946	23 972 456	23 911 000	70 175 519
		EEK/t kaevist	9,41	7,87	9,03	14,85
Tegevuskulud (kontori, IT jne)		EEK	13 700 245	10 212 286	8 545 000	16 233 909
		EEK/t kaevist	1,64	3,35	3,23	3,43
Kulud rajatistele ja hoonetele						
		EEK	10 250 755	2 944 855	9 572 000	8 785 974
		EEK/t kaevist	1,23	0,97	3,62	1,86
Admin palgad	inimeste arv	admin in/mln t kaevis	27,21	33,42	23,81	19,24
		in	227	102	63	91
		EEK/kuu	9 350	8 816	7 254	8 002
		Palgamaksud	1,335	1,335	1,335	1,335
		EEK	33 995 191	14 383 213	7 324 169	11 654 773
Elekter	väljapumb vee kohta	kWh/m³	0,39	0,29	0,16	0,19
	veekõrvaldus	EEK/m3 (vesi)	0,25	0,18	0,09	0,12
MUUTUVKULUD						
Väljamine ja otsesed mäetööd						
Ankurtoestik	õõnestatud ala	EEK/m2 (õõnestatud ala	8,73	8,17		
Katendis kasut lõhkematerj kulu	Lõhkeaine erikulu lõhatud katendile	kg/m3			0,96	0,57
	Lõhkeaine erikulu lõhatud kaevisele ja kraavile	kg/m3	0,59	0,61		
		EEK/m3	6,21	6,45		
	Lõhkeaine erikulu lõhatud kaevisele ja kraavile	EEK/m3	3,62	4,25		
		EEK/m3			5,36	5,03
Lõhkeained ja materjalid	pealmaa toodang ja veekraav	EEK/m3(kaevis)			3,28	2,26
	allmaakaevandamine	EEK/m3(kaevis)	9,83	10,70		
Puurinstrumendid	toodang ja veekraav	EEK/m3 (kaevis)	0,91	1,18	0,13	
Muud materjalid (metsamaterjalid, muud)		EEK/m3	2,97	1,14	1,07	3,23
Elekter	hind	EEK/kWh	**0,62**	**0,63**	**0,59**	**0,60**
erikulu	kaevandamine	kWh/m³ (kaevis)	1,2	1,4	1,3	1,8
		EEK/m3	0,77	0,91	0,77	1,05
	tuulutus	kWh/m³ (kaevis)	3,04	4,66		
		EEK/m3	1,89	2,93		
erikulu	kaevisele	kWh/m³	3,0	1,4	2,3	4,2
	muu tarbimine	EEK/m3	1,86	0,89	1,35	2,54
	alajaotuse	EEK/m3	6,43	6,51	4,87	4,03
Mäetööliste palk		EEK/kuu	9 350	8 816	7 254	8 002
	kokku töölistele	in/aastas*m3(kaevis)	313	390	248	298
		EEK/m3(kaevis)	47	55	29	38
	ei sisald rikast ja katendit	in/aastas*m3(kaevis)	294	366	189	259
		EEK/m3(kaevis)	44	52	22	33
Kulud töövahenditele	materj, varuosad, hooldus, muud	EEK/m3(kaevis)	11	12	11	22
	eelmine-(miinus) rikast	EEK/m3(kaevis)	9	9	7	22
	kütus	EEK/m3	4,31	4,01	2,38	8,33
Kaevanduse transport						
Elekter	allmaatransport	kWh/(m³*km) (kaevis)	0,6	0,4		
		EEK/m3	2,48	1,86		
Kulud transpordivahenditele	materj, varuosad, hooldus, muud	EEK/m3(kaevis)*km	0,15	0,30		
	kütus	EEK/m3(kaevis)*km	0,16	0,14		
Kulud transpordivahenditele	materj, varuosad, hooldus, muud	EEK/m3(kaevis)*km			0,42	0,34
	kütus	EEK/m3(kaevis)*km			0,83	0,74
Katendi teisaldamine						
Elektrienergia	paljandustööd	kWh/m³			1,91	1,41
		EEK/m3(katend)			1,12	0,85
	Puurmasinad	EEK/m3 (kaljune)			0,22	0,07
Materjalid	lõhkeaine	EEK/m3(kaljune)			4,73	4,84
	lõhkematerjalid	EEK/m3(kaljune)			0,63	0,20
	Lõhkematerjalid KOKKU	EEK/m3(kaljune)			5,36	5,03
	Ekskavaatoritele	EEK/m3 (kaljune)				0

MÄETEHNILISED LÄHTEANDMED						
			Estonia	Viru	Aidu	Narva
Kaevandamismeetoodika			Kamber, rikastami	Kamber, rikastar	Lausväljamine,r	Selektiivne
Almaa - 0; pealmaa - 1			0	0	1	1
Kauba energiatootlus		GJ/m2	39,90	41,44	43,11	39,03
Kaevise massitootlus (niiske)		t/m2	6,12	5,44	5,31	3,62
Kauba massitootlus (niiske)			3,54	3,47	3,87	3,65
Põlevkivikihtide bilansiline massitootlus		t/m2	3,30	3,29	3,55	3,01
Kaevise keskmine kütteväärtus		GJ/t	7,24	8,32	8,88	10,69
Tootsa kihindi paksus		m	3,12	2,91	3,03	2,04
Kaljused kivimid		m	50,00	30,00	9,00	9,72
		tuh m3	0	0	4 485	12 685
Kvaternaarisetted ja pinnas		m	15,00	10,00	3,81	6,86
		tuh m3	0	0	1 899	8 952
Katend kokku		m	65	40	12,81	16,58
		tuh m3	0	0	6 384	21 637
Veokaugus		km	6,8	8,4	6,6	7,63
Vajalik väljatav ala	õõnes ala	tuh m2	1 363	560	498	1 305
	koos kadudega (kasutatud ala)	tuh m2	1 745	700	518	1 462
Väljatav kaevise maht		tuh m3	4 254	1 631	1 510	2 662
Rikastusjäätmed		tuh t	3 627	1 141	0	0
Väljapumbatava vee kogus		tuh m3	81 424	21 934	63 069	71 656
Kaod			0,28	0,25	0,04	0,12
Tootmiskaod					0,04	0,12
Kaod tervikus			0,28	0,25		
Aheraine kütteväärtus		MJ/kg	2,00	2,26	2,87	0
Kauba energiakogus		PJ	53	23	21	51
Kauba osalus põlevkivikihindis			56,5%	62,6%	72,7%	100,0%
Aheraine osalus põlevkivikihindis			43,5%	37,5%	27,3%	0,0%
Väljatava kaevise mass		tuh t	8 338	3 047	2 647	4 726
Kihindi NIISKE mahumass küttevärtuse järgi (Kattai valem)		t/m3	1,96	1,87	1,75	1,78
Kihindi KUIV mahumass küttevärtuse järgi (Kattai valem)			1,80	1,74	1,71	1,62
Kihindi niiskusesisaldus		%	8,67	7,25	2,40	9,37
Kattai valemi parandus					0,00	0,00
Kogu kaevise mahumass			1,960	1,869	1,753	1,775

KESKKONNATASUD						
Põlevkivi ressursimaks		EEK/t	5,135	5,135	5,135	5,135
Veekasutustasu		EEK/m3	0,067	0,067	0,067	0,067
Jäätmemaks		EEK/t	2,30	2,30	0,00	0,00
Kasutatud põlevkivivaru (s.h. tervikutesse jäetud)		tuh t	5 753	2 305	1 842	4 401
Veekasutus		tuh EEK	5 415	1 459	4 194	4 765
Heitvesi		tuh EEK	1 360	383	1 995	1 555
Välisõhu saaste		tuh EEK	13	13	13	14
Põlevkivivaru kasutamise tasu		tuh EEK	29 542	11 834	9 461	22 599
Jäätmetasu		tuh EEK	8 342	2 625	0	0

MÜÜGIKOGUSE TABEL						
Eesti Elektrijaam		tuh t	3 848	1 194	0	4 726
Balti Elektrijaam		tuh t	0	0	1 717	0
Aidu Oil OÜ		tuh t	0	0	0	0
Kiviõli Keemiatööstus OÜ		tuh t	0	0	208	0
Viru Õlitööstuse AS		tuh t	863	712	0	0
AS Kunda Nordic Tsement		tuh t	0	0	0	0
Sillamäe SEJ		tuh t	0	0	0	0
Ahtme EJ		tuh t	0	0		0
KOKKU		tuh t	4 711	1 906	1 925	4 726
	MIN		0	0	0	0
	MAX		5 000	2 200	2 200	5 000

MÜÜGIKOGUSE TABEL, kuiv mass						
Eesti Elektrijaam		tuh t	3 425	1 062	0	4 206
Balti Elektrijaam		tuh t	0	0	1 528	0
Aidu Oil OÜ		tuh t	0	0	0	0
Kiviõli Keemiatööstus OÜ		tuh t	0	0	185	0
Viru Õlitööstuse AS		tuh t	768	634	0	0
AS Kunda Nordic Tsement		tuh t	0	0	0	0
Sillamäe SEJ		tuh t	0	0	0	0
Ahtme EJ		tuh t	0	0	0	0
KOKKU		tuh t	4 193	1 696	1 713	4 206
	MIN		0	0	0	0
	MAX		5 000	2 200	2 200	5 000

ÜLEMISTE KÜTTEVÄÄRTUSTE TABEL						
Eesti Elektrijaam		MJ/kg	10,70	10,78	0,00	10,69
Balti Elektrijaam		MJ/kg	0,00	0,00	10,82	
Aidu Oil OÜ		MJ/kg				
Kiviõli Keemiatööstus OÜ		MJ/kg			13,82	
Viru Õlitööstuse AS		MJ/kg	13,84	13,89	0,00	
AS Kunda Nordic Tsement		MJ/kg			0,00	
Sillamäe SEJ		MJ/kg		0,00	0,00	
Ahtme EJ		MJ/kg		0,00		
Müüdud põlevkivi keskmine kütteväärtus		MJ/kg	11,27	11,94	11,14	10,69
	MIN		10,000	10,000	10,000	10,000
	MAX		14,000	14,000	14,000	14,000

NIISKUSESISALDUS						
Eesti Elektrijaam		MJ/kg	11,00	11,00	11,00	11,00
Balti Elektrijaam		MJ/kg	11,00	11,00	11,00	
Aidu Oil OÜ		MJ/kg				
Kiviõli Keemiatööstus OÜ		MJ/kg			11,00	
Viru Õlitööstuse AS		MJ/kg	11,00	11,00	0,00	
AS Kunda Nordic Tsement		MJ/kg			0,00	
Sillamäe SEJ		MJ/kg		0,00	0,00	
Ahtme EJ		MJ/kg		0,00		
Müüdud põlevkivi keskmine kütteväärtus		MJ/kg	11,00	11,00	11,00	11,00
	MIN		10,000	10,000	10,000	10,000
	MAX		14,000	14,000	14,000	14,000

ALUMISTE KÜTTEVÄÄRTUSTE TABEL						
Eesti Elektrijaam		MJ/kg	8,52	8,59		8,52
Balti Elektrijaam		MJ/kg			8,62	
Aidu Oil OÜ		MJ/kg				
Kiviõli Keemiatööstus OÜ		MJ/kg			11,13	
Viru Õlitööstuse AS		MJ/kg	11,15	11,19		
AS Kunda Nordic Tsement		MJ/kg				
Sillamäe SEJ		MJ/kg				
Ahtme EJ		MJ/kg				
Müüdud põlevkivi keskmine kütteväärtus		MJ/kg	9,00	9,56	8,89	8,52
	MIN		10,000	10,000	10,000	10,000
	MAX		14,000	14,000	14,000	14,000

ENERGIAKOGUSTE TABEL, kuiva järgi						
Eesti Elektrijaam		PJ	36,6	11,5	0,0	45,0
Balti Elektrijaam		PJ	0,0	0,0	16,5	0,0
Aidu Oil OÜ		PJ	0,0	0,0	0,0	0,0
Kiviõli Keemiatööstus OÜ		PJ	0,0	0,0	2,6	0,0
Viru Õlitööstuse AS		PJ	10,6	8,8	0,0	0,0
AS Kunda Nordic Tsement		PJ	0,0	0,0	0,0	0,0
Sillamäe SEJ		PJ	0,0	0,0	0,0	0,0
Ahtme EJ		PJ	0,0	0,0	0,0	0,0
Müüdud põlevkivi keskmine kütteväärtus		PJ	47,3	20,3	19,1	45,0
	MIN					
	MAX					

VEOKAUGUSTE TABEL

KLIENDID			Estonia	Viru	Aidu	Narva
Eesti Elektrijaam	Mustajõe	km	46	38		11,9
Balti Elektrijaam	Narva	km			67	
Aidu Oil OÜ	Püssi ?	km				
Kiviõli Keemiatööstus OÜ	Kiviõli	km			10	
Viru Õlitööstuse AS	K-Järve	km	36	17	17	
AS Kunda Nordic Tsement	Kunda	km			62	
Sillamäe SEJ		km		31		
Ahtme EJ		km		6		

TRANSPORDIHINNA TABEL

Eesti Elektrijaam		EEK/(t*km)	0,32	0,32	24	0,32
Balti Elektrijaam		EEK/t	24	24	24	24
Aidu Oil OÜ		EEK/(t*km)	0,32	0,32	0,32	0,32
Kiviõli Keemiatööstus OÜ		EEK/(t*km)	0,32	0,32	0,32	0,32
Viru Õlitööstuse AS		EEK/(t*km)	0,32	0,32	0,32	0,32
AS Kunda Nordic Tsement		EEK/t	24	24	24	24
Sillamäe SEJ		EEK/(t*km)	0,32	0,32	0,32	0,32
Ahtme EJ		EEK/(t*km)	0,32	0,32	0,32	0,32

Appendix 1 continued

TOOTMISKULUDE TABEL

Heitvee, välisõhu saaste maksu kasvamine			1	1	1	1
Püsikulud						
Kas tootmine toimub			1	1	1	1
Admin töötajate palk		tuh EEK	33 995	14 383	7 324	11 655
Muud püsikulud		tuh EEK	122 399	41 119	47 788	103 456
	Kulum	tuh EEK	78 449	23 972	23 911	70 176
			16,65	12,58	12,42	14,85
	Tegevuskulud (kontori, IT jne)	tuh EEK	13 700	10 212	8 545	16 234
			2,91	5,36	4,44	3,43
	Kulud rajatistele ja hoonetele	tuh EEK	10 251	2 945	9 572	8 786
			2,18	1,54	4,97	1,86
	elekter (veekõrvald)	tuh EEK	19 999	3 989	5 760	8 261
			4,25	2,09	2,99	1,75
KOKKU		tuh EEK	163 182	57 357	61 314	121 445
		Osalus	28%	25%	32%	26%
Muutuvkulud						
Materjalid		tuh EEK	78 847	31 273	37 232	81 557
		EEK/t	16,74	16,41	19,34	17,26
s.h.	Kaevandamine	tuh EEK	70 225	25 804	6 774	14 606
	Katend	tuh EEK	0	0	24 591	66 951
	Rikastamine	tuh EEK	8 621	5 469	5 867	0
Elektrienergia		tuh EEK	37 893	13 651	15 495	29 965
		EEK/t	8,04	7,16	8,05	6,34
s.h.	Kaevandamine	tuh EEK	29 747	10 758	3 201	9 566
	Katend	tuh EEK	0	0	8 142	19 246
	Rikastamine	tuh EEK	8 145	2 893	4 152	1 153
Tööjõud ja põhivahendid		tuh EEK	66 555	26 627	27 122	102 374
		EEK/t	14,13	13,97	14,09	21,66
s.h.	Kütus	tuh EEK	22 920	8 407	11 865	37 207
	Materjalid, varuosad, hooldus, muud	tuh EEK	43 635	18 221	15 257	65 167
Tootmistööliste palk		tuh EEK	199 337	89 889	43 547	101 021
s.h.	Kaevandamine	tuh EEK	187 193	84 208	33 184	88 260
	Katend	tuh EEK	0	0	4 013	12 762
	Rikastamine	tuh EEK	12 144	5 681	6 350	0
KOKKU		tuh EEK	420 515	175 899	132 856	337 515
Kulud kokku		tuh EEK	583 698	233 256	194 170	458 960
		EEK/t	123,9	122,4	100,9	97,1
		EEK/GJ	12,4	11,5	10,2	10,2

Kaevandamiskulud

Kulud kokku		mln EEK	584	233	194	459
sh püsikulud		mln EEK	163	57	61	121
mutuvkulud		mln EEK	421	176	133	338
Transpordi- ja tootmiskulud		mln EEK	650	252	236	477
		EEK/t	138,0	132,0	122,6	100,9
		EEK/GJ	13,8	12,4	12,4	10,6
Kas tootmises on neg arve			1	1	1	1

Kontrollarvutus	arvutuslikud keskkonnatasud		44 672	16 313	15 663	28 933
Keskkonnatasud	baasvarIANT	EEK	44 672	16 313	15 299	26 511
	vahe		0	0	-364	-2 421
	kulud kokku		583 698	233 256	193 806	456 539
	omahind	EEK/t	123,90	122,37	100,67	96,59

KULUD KULUARTIKLITE KAUPA

Palk			233 332	104 272	50 872	112 676
Elektrienergia			57 892	17 640	21 255	38 226
Kerged vedelkütused (diisel)			22 920	8 407	11 865	37 207
Materjalid			122 482	49 494	52 489	146 724
XXXXX			23 951	13 157	18 117	25 020
Keskkonnatasud			44 672	16 313	15 663	28 933
Kulum			78 449	23 972	23 911	70 176
			583 698	233 256	194 170	458 960

KULUARTIKLITE OSALUS KULUDES

Palk			40,0%	44,7%	26,2%	24,6%
Elektrienergia			9,9%	7,6%	10,9%	8,3%
Kerged vedelkütused (diisel)			3,9%	3,6%	6,1%	8,1%
Materjalid			21,0%	21,2%	27,0%	32,0%
XXXXX			4,1%	5,6%	9,3%	5,5%
Keskkonnatasud			7,7%	7,0%	8,1%	6,3%

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FORECAST OF ESTONIAN OIL SHALE USAGE FOR POWER GENERATION

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Power generation of Estonia is based on oil shale today. The share of oil shale in power generation is over 90 per cent. According to prognoses of Estonian economic growth, the need for energy will grow and even if applying alternative power sources, it cannot be realistic that it could be reduced to less than 50 per cent of today's volumes in 2020. Because of the increasing cost of crude oil, oil generation from shale is of growing importance. But oil shale is very rich in ash, which results in huge amounts of solid residues. In addition Estonian oil shale has a great content of carbonate minerals thus combusting and oil processing is accompanied by abnormally high emissions of CO_2*. Though emission of sulphur dioxide is low due to carbonate minerals, limitation of* SO_2 *pollution is expected in the near future. In relation to growing environmental requirements, the interest towards utilisation of oil shale of higher calorific value has grown. As it is clear that higher calorific value of product causes higher production expenditures, the question arises where is the optimal point. Consumers are interested in a fuel raw material of higher quality. Upgrading of oil shale results in higher operating expenses and requires also applying of a new price scale. Optimizing the grade of the oil shale as well as the quality of the shale oil to best fit the interests of the mines and consumers is the subject of this paper.*

Introduction

Use of oil shale of higher calorific value improves the technical efficiency of the equipment used [1–3]. Transportation expenditures are reduced. Also, use of oil shale of higher heat value results in reduced amounts of ash.

The useful component of oil shale is kerogen (organic matter). The main quality indicators are calorific value (Q) and oil yield (T). Calorific value and oil yield of oil shale are proportional to kerogen content. As kerogen's calorific value is 35±3 MJ/kg, the formula of oil shale calorific value (of dry matter) is

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$$Q = 35\,K, \text{ MJ/kg},$$

where K is the share of kerogen (100% = 1), and oil yield is

$$T = 65.5\,K = 1.86\,Q\ \%.$$

There are two sources of CO_2 from oil shale combustion: decay of carbonate minerals and combustion of kerogen. Higher heat value of oil shale indicates lower share of carbonate minerals and this can be improved by using different treating techniques in mines. The CO_2 from combustion of kerogen will be introduced to carbonous CO_2 but decreasing of that is not possible by mining. The amount of CO_2 formed at full decay of carbonate minerals of oil shale also depends on the content of organic matter in fuel:

$$CO_2 = 0.4\,K^2 - 0.8\,K + 0.4.$$

Ash content (A) also depends on quality of oil shale:

$$A = -0.4\,K^2 - 0.2\,K + 0.6.$$

The quality of oil shale can be improved in mines by separating run-of-mine (ROM) oil shale and selective extraxtion of oil shale and limestone layers.

Oil shale consumers use different equipment in their technological process. Power plants have boilers for pulverized oil shale firing (POS-firing). A comparatively new technology in the power industry is circulating fluidized bed firing (CFB-firing). Shale oil producers have been using vertical retorts for processing lump oil shale (LOS-process) since the twenties. News is oil generators with solid heat carrier (SHC-process) and some new plants are planned to put in operation soon. To solve the optimizations task the requirements of different process technologies of the different consumers need to be known.

Trends of oil shale use in the foreseeable future

To forecast developments of the Estonian economy and those of other countries, the economic, technological, social, ecological and political aspects must be analyzed. This has been done, but the results are beyond the scope for this paper. However, some postulates are given:

- Economical and technological advancements can be forecasted up to 20 years
- Consumption of power depends on economic growth
- There is no option to get rid of oil shale in power production in the foreseeable future
- Growth of oil price is inevitably followed by increasing amounts of production of shale oil

The first and second postulates are discussed. The second postulate serves as a base to draw three scenarios for Estonian economy.

Overoptimistic scenario of economic growth. Estonian economy reaches the level of the richest European countries in 15 years. To achieve that, Gross National Product (GNP) has to grow four times from the present level by the year 2020, 10 per cent annually on average. The share of competitive power sources like wind generators, combined power plants and bio-electricity (broadly speaking "soft" electricity) will be 20 per cent. The share of natural gas in power generation will not grow over 10 per cent. A nuclear power plant in the Baltic region will be built in 10 years and obviously it will be interstate. Estonia will continue export about 2 TWh of power.

The overoptimistic scenario responds to the present (2007) program of the Estonian government. Accomplishing the program assumes strong involvement of the government to economic development. This means that the price of electricity has to be held in correlation with economic growth, having the value of 0.25 EUR/kWh in 2020. A strong sustainable power consumption policy is essential. Development of nuclear energy is essential but difficult due to environmental radicalism that has developed in Estonia in the past years.

Intermediate scenario of economic growth. GNP grows three times till the year 2020, or 8 per cent annually on average. The share of soft electricity is the same as in the previous scenario. A nuclear power plant will be built in 15 years. It is still remained undecided whether it will cover power needs of Estonia or also of some other countries. Estonia will continue to export about 1 TWh of power annually.

Moderate scenario of economic growth. GNP will grow two times till the year 2020, 5 per cent annually on average. The share of soft electricity is the same as in previous scenarios. A nuclear power plant will not be operating in the foreseeable future and Estonia's share in interstate nuclear projects is negligible. Estonia cannot export power.

The moderate scenario provides that government will continue its present liberal policy. But there are disadvantageous factors such as lack of training of a qualified work force and engineers; less use of labour- and energy-intensive technology; and buckling under radical environmentalism decelerating the growth.

Demand of electricity

It seems natural that volume and structure of power consumption and its relation to GNP in Estonia is similar to North European countries that are situated in the same climate. Power consumption depends on the economic state of the country – the higher the GNP, the higher the power consumption or energy-intensiveness of GNP. This statement is illustrated in Fig. 1.

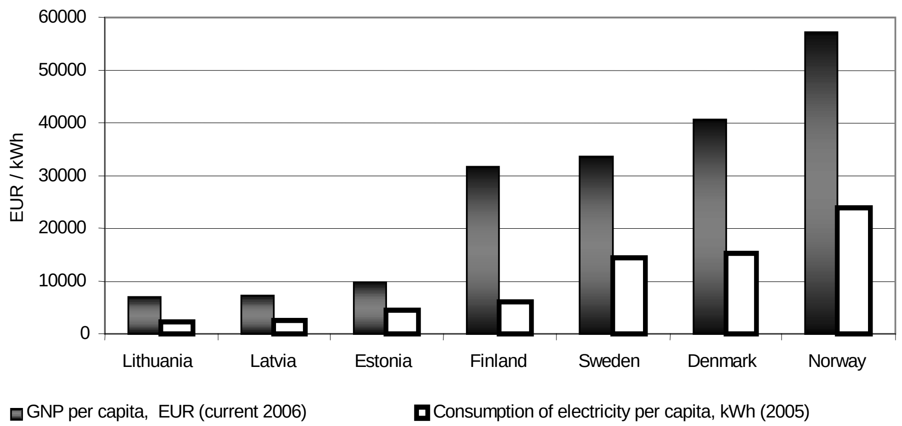

Fig. 1. GNP per capita (current prices 2006) and consumption of electricity by industry, transport activities and households/services in 2005 according to Eurostat [4].

Taking economic growth of Estonia between 2000 and 2006 as a base case, we could calculate electricity consumption according to elasticity in reference to GNP. An exponent or an elasticity of 0.51 (Fig. 2) indicates that one per cent growth of GNP calls for approximately 0.51 per cent growth in power consumption. However, as can be read from Fig. 3, elasticity of electricity consumption is lower for countries of higher economic levels. It can be concluded that, if reaching a GNP per capita to a value of 23 thous EUR in the future, the power elasticity of GNP decreases twice. Using the data above, the case can be made that for an overoptimistic economic prognosis, electricity consumption in Estonia will decline. It also applies in the case of the intermediate economic prognosis. In relation to this paradox we carry forward only a moderate scenario of development.

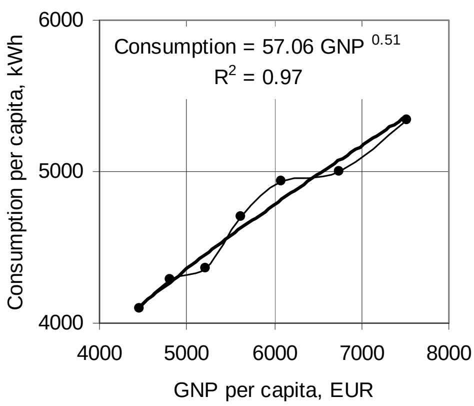

Fig. 2. Dependence between electricity consumption and GNP per capita.

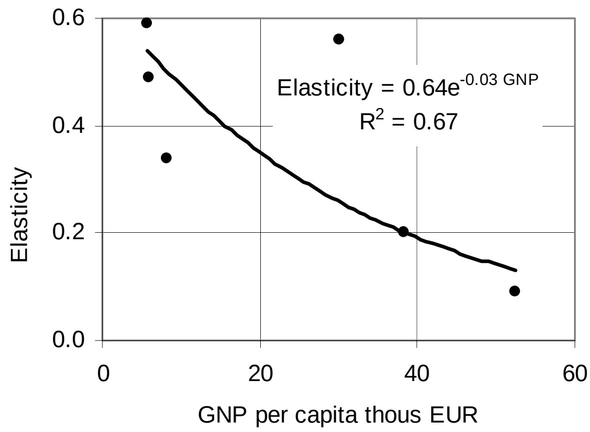

Fig. 3. Dependence between elasticity of power consumption and GNP in 2005 values (countries according Fig. 1, does not include Sweden).

Moderate scenario of electricity consumption and production

Following applies providing that population of Estonia does not change. In addition, let us assume that power losses in the supply net will be reduced and will be less than 10 per cent beyond the year 2010. Ungrading oil shale will reduce the specific quantity of fuel on power production and is estimated to be 1.1 kg per kWh after 2016. The proportion of pulverized fuel will decline, which reduces the need for milling of oil shale fuel resulting in reduced fuel consumption by power plant to the level of 9 per cent by 2020.

Two POS-firing boilers in the Narva power plants are expected to be replaced with 300 MW CFB boilers: the first one in 2011–2013 and the next one in 2016. The last POS boiler is expected to be installed in 2016. As a nuclear power plant is not expected to be built in the foreseeable future, the output of power plants will not be reduced and closure of the old CFB boiler will begin after 2025.

Moderate scenario of shale oil production

Shale oil is already competitive with current crude oil prices. However, options to expand the shale-oil industry are unclear because environmental problems are greater in processing shale oil than in power generation. Considering the current situation, we can assume that with increasing production of shale oil, environmental sensitivity will grow progressively. According to data currently available, the Estonian Energy Company will have at least two SHC-generators by 2011. The *Viru Keemia Group* (VKG) is planning to place on line two SHC-generators – the first in 2010 and the second in 2012. Additional generators are planned depending on opening new mines located in the western part of the Estonia oil shale deposit. The SHC-generator of Kiviõli shale oil plant is expected to reach full output in 2008.

As the quality of oil shale to fire the CFB boilers and the SHC-generators of power plants is raised, the Estonia and Viru mines will probably cut production and selling of lump oil shale for the old LOS-generators of VKG. These old generators will be closed in 2011 at latest when the first SHC generator of VKG is expected to reach its full output.

According to such a scenario the annual oil shale output for domestic needs will not grow over 15 mill tonnes annually in the period of prognosis (2008–2020) (Fig. 4).

However, it is obvious that higher quality causes higher operating costs for mines and reduces interest of consumers. Therefore, the prognosis cannot be complete without considering economical opportunities of consumers.

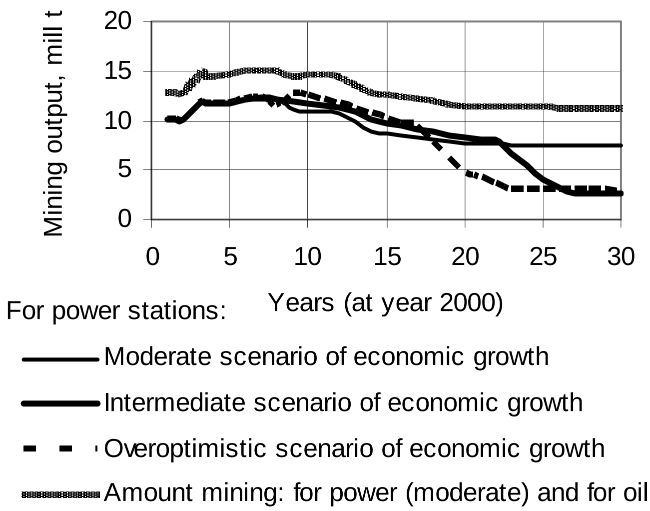

Fig. 4. Forecast oil shale mining output according to economic growth scenarios.

Dependence between oil shale quality and price

As mentioned above the amount of oil shale required in oil and power plants depends on its quality. Higher quality can be achieved by sorting the run-of-mine or by selective mining. In both cases higher quality results in decreased recovery. The theoretical background of this problem is expanded upon in the literature [1, 2]. Another factor having an influence on quality and expenses is the difference in mining conditions in the various districts of the oil shale field. It is known that the natural quality of oil shale in different fields of the deposit varies. It is more expensive to ensure good quality in worse mining conditions (i.e., the Estonia underground mine and the eastern part of the Narva opencast mine) than in mines where conditions are better (i.e., the Viru mine and the Viivikonna field in the Narva opencast mine). Obtaining the necessary amount of oil shale of high quality in different conditions is a classical optimization task that has been handled in previous studies [5].

Neither of previous studies has really considered oil shale as an energy carrier. If optimizing oil shale production, it has to be done with a real commodity that is the (useful) energy of oil shale. Figuratively, oil shale is a package, an energy carrier, and energy is wrapped into it.

The dependence between the calorific value of oil shale and the product's operating and transportation expenses in the Viru mine, as an example, is illustrated in Fig. 5 and 6. It has been considered in calculations that the mine has to supply consumers with oil shale in amounts that assures 22.8 PJ of energy in a year. Different quality values of trade oil shale are entered into the model and the respective operating expenses and oil shale prices are calculated. Figures are given for one mine, as an example, related calculations have been made for different mines. If expressed in per cent ratios, operating expenses grow faster than calorific value (Fig. 7). If the heat value of trade oil shale is increased by one per cent then operating expenses grow a bit more than one per cent.

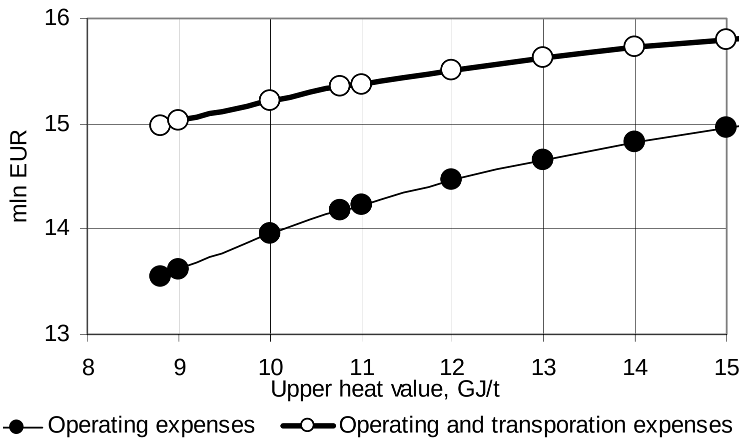

Fig. 5. Relation between upper heat value and expenses for mine giving total energy amount of 22.8 PJ.

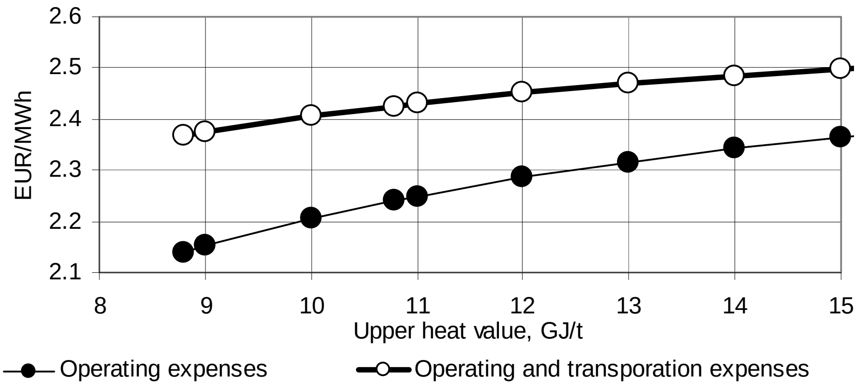

Fig. 6. Relation between energy cost and heat value in mine giving total energy amount of 22.8 PJ.

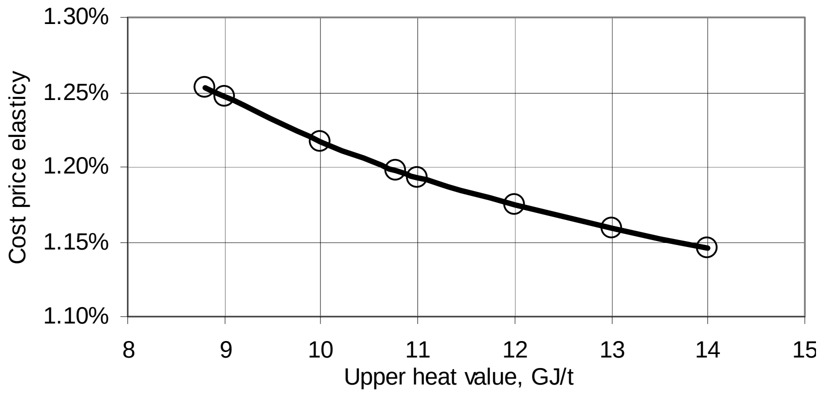

Fig. 7. Increase of cost price with one per cent rise of heat value of oil shale.

Table shows the reduction in income caused by increased operating expenses. Incomes remain the same as current output does not state that selling price is fixed and does not depend on quality. There is only fixed minimum value of quality. Every energy unit above that value means an economic loss for mine.

Table. **Increase of operating expenses if giving oil shale of higher heat value than agreed**

Features	Case 1	Case 2	Case 3
Agreed heat value (lower heat value), GJ/t	8.4	8.6	8.6
Amount of mined oil shale, 10^3 t	1 194	1 194	1 167
Amount of mined oil shale for oil producers, 10^3 t	712	712	712
Upper heat value of fuel oil shale, GJ/t	10.70	10.94	10.94
Lower heat value of fuel oil shale, GJ/t	8.4	8.6	8.6
Moisture content of fuel oil shale, %	12	12	12
Heat value of oil shale for oil producers, GJ/t	13.89	13.89	13.89
Amount of energy in fuel oil shale, PJ	12.8	13.1	12.8
Amount of energy in oil shale for oil producers, PJ	9.9	9.9	9.9
Cost price of trade oil shale, EUR/t	7.55	7.64	7.67
Operating expenses, 10^3 EUR	14 391	14 562	14 425
Increase of operating expenses, 10^3 EUR		171	35
Less income from sales (in oil shale price of 7.81 EUR/t)			206
Total loss, thousand EUR			241

Notes for Table:

Case 1 in the table is when mine gives fuel oil shale of exactly agreed quality.

Case 2 shows a simplified calculation of economic loss. The calculation provides that the mine sells the same amount of oil shale as in Case 1 but with a higher heat value of 0.2 GJ/t. This assumption does not consider the fact that the consumer's commodity is energy and if the energy content of oil shale it gets is higher, it needs less tonnes of oil shale.

Case 3 considers the reduced demand of oil shale while energy contained in it remains the same. The economic loss is considerably higher than in Case 2.

Conclusions

1. According to a moderate scenario of Estonian economic growth, it is probable that consumption of oil shale in next 15-20 years will not decrease.
2. It would be reasonable to increase the heat value of oil shale in order to utilise oil shale sources more efficiently and with less environmental impact.
3. The mathematical model of oil shale energy flow allows us to evaluate the operating expenses and the increase of sale price accompanied by an increase of oil shale quality.
4. Optimization of oil shale energy flows and rising of heat value requires also applying new price scale.

Acknowledgements

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Oil shale reserves in Estonia

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Abstract

The aim of current paper is to show different approach to determine oil shale resources than it is conventional. The resources of Estonian kukersite oil shale are determined as mass production of oil shale layers A…F. The alternative option to calculate resources is based on seam heating value and energy rating of seam on one hand meeting requirements of oil shale utilising power plants or oil factories on the other hand.

Introduction

Along with rapid growth of price of crude oil in recent past Estonian oil shale has earned great attention and interest in opening new sources is in its peak. Several companies have shown up great interest and several claims have been handed to exploit potential mining areas. The question is where to set limits of volumes to exploit the Estonian deposit and how long will the resources last.

The first question which appears is how big the reserves of Estonian oil shale are. It has to be mentioned, that there are two different kinds of oil shale in Estonia – kukersite oil shale and Dictyonema shale. Presently Dictyonema shale is not considered as a mineable resource.

Determining oil shale reserves

The basic criterion to determine Estonia's resources of kukersite oil shale is the energy rating of the bed of all oil shale layers A-F and limestone interlayers in GJ/m^2. Oil shale resources are considered to be active if the energy rating of a bed is above 35 GJ/m^2. As shown in the Table 1 Kukersite oil shale field is divided into exploration blocks. Today oil shale resources are calculated as mass production of oil shale layers A…F. Actual treating technology is more complicated and trade oil shale is diluted by limestone from interlayes and roof.

Table 1. Oil shale resources

Name of block/field	Area of block/field, ha	Seam depth, m	Seam thickness, m	Seam heating value, GJ/t	Reserves in the block, thous t	Energy rating of a bed, GJ/m2	Useable oil shale resource, thous t	Available energy source, PJ
AHTME	5 065,5	*33...56*	*2,76*	9,9	226 089	44,3	115 448	1 385
AIDU	3 197,0	20	2,80	8,2	158 712	40,8	93 602	1 123
ESTONIA	18 399,2	20…65	2,69	8,3	885 498	40,0	344 537	4 134
KOHTLA	2 535,8	*7…26*	*2,83*	9,2	118 747	43,1	67 096	805
NARVA	6 187,9	9…39	2,63	8,6	259 443	35,9	139 984	1 680
OJAMAA	3 482,6	30…41	2,59	9,2	145 672	38,7	58 538	702
P-KIVIÕLI	1 268,3	11…16	2,67	7,3	62 859	36,1	27 401	329
PUHATU	15 359,8	38…74	2,68	8,4	695 448	38,0	154 152	1 850
SELI	8 620,7	54…65	2,50	7,1	407 547	33,5	83 344	1 000
SIRGALA	6 032,8	23…26	2,55	9,5	262 892	41,4	138 352	1 660
SOMPA	3 358,8	31	2,63	10,2	142 507	43,4	81 539	978
TAMMIKU	5 109,3	12	2,68	9,5	243 787	45,2	88 051	1 057
UUS- KIVIÕLI	6 174,4	22…33	2,60	8,8	263 161	37,5	127 635	1 532
VIRU	4 165,9	46...53	2,72	9,1	197 213	43,1	98 293	1 180
Total	271 932						**1 617 971**	**19 416**

Therefore talking of tons makes the subject in one hand clear (tons are simple unit to for common understanding) in the other hand more hazy. The major presumption in that way is to specify what the oil shale mined for. If talking about oil shale mining, it is almost always about tons mined. But it is good to remind that it is not rock what oil shale is mined for, but energy it contains. As it was mentioned oil shale seam is not homogenous; it consists of oil shale layers altered by limestone layers. To be used in industry oil shale has to meet certain quality requirements. The most important is calorific value. The run-of-mine material is not suitable for power generating in power plants (fuel oil shale) or oil production. It has to be treated in separation plant to remove the waste rock with lower calorific value.

Today oil shale of about 8,5 MJ/kg of lower heating value is used mostly for power generating and 11,4 MJ/kg for oil production. In higher heating values those numbers are respectively about 11 MJ/kg and 14 MJ/kg. If we know the heating value of the seam and make an assumption that oil shale of average heating value of 12 MJ/t is needed and waste rock has heating value of 2 MJ/kg, we can calculate the balance of trade oil shale and waste rock.

Determining sources of oil shale is shown in Table 1. Exploration blocks with energy rating of higher than 35 GJ/m^2 are taken into account. Oil shale under preserve and built-up areas are subtracted from reserves as well as mining losses which are 4-12 % for surface and 25-30 % for underground operations. Energy in amount of more than 19 000 PJ is available. In comparison, the Estonian biggest oil shale producer Eesti Põlevkivi Ltd sold oil shale in amount of total energy of about 150 PJ in 2005/06 economical year.

As a final remark, it should be noticed that numbers mentioned above are mostly taken as ultimate and any deflections are undesired. Any Joule above that value is considered as loss for miners, any Joule less is loss for electric power or oil producers. Actually, oil shale based power and oil production should be handled as one whole sequence and to make it economically most feasible all the links including mining, transportation and final utilization in power plant or oil factory should be optimized on cost and benefit basis.

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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

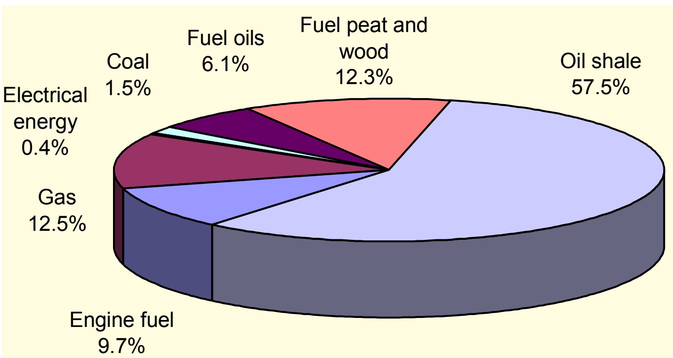

Fig. 1. Balance of primary energy in Estonia in 2000

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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.

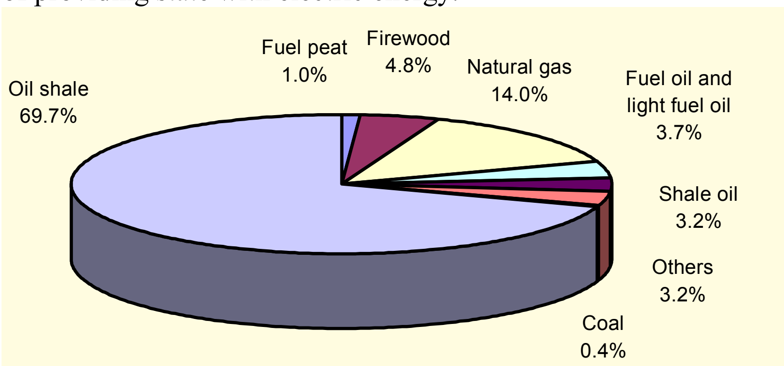

Fig. 2. Estonia's consumption of fuels for producing electricity and heat

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).

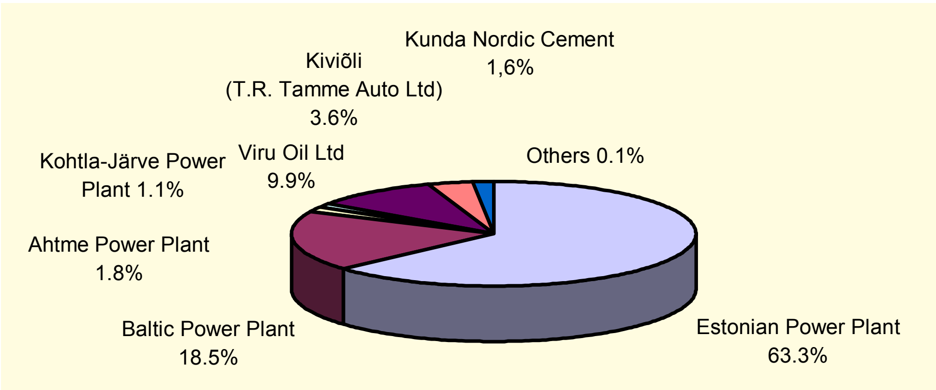

Fig. 3. Oil shale consumers in 2000

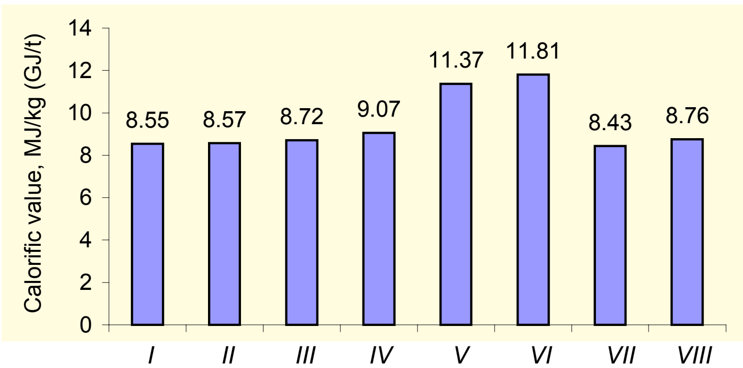

Fig. 4. Consumers' demands in oil shale quality in 2000: *I* – Estonian Power Plant; *II* – Baltic Power Plant; *III* – Ahtme Power Plant; *IV* – Kohtla-Järve Power Plant; *V* – *Viru Oil* Ltd; *VI* – Kiviõli (*T.R. Tamme Auto* Ltd); *VII* – *Kunda Nordic Cement*; *VIII* – others

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).

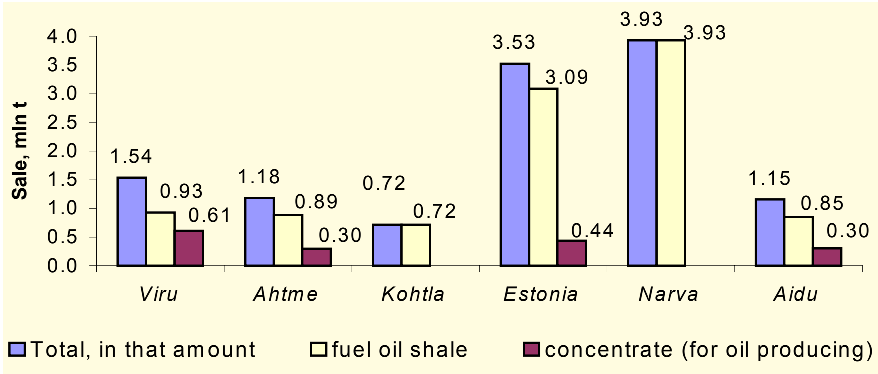

Fig. 5. Sale of oil shale by enterprises in 2000

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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Underground mining challenges for Estonian oil shale deposit

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Overview of oil shale in Estonian power industry

Estonian power industry is characterized by great share of oil shale - oil shale is the main energy source for power generation and has its part in heat energy. The share of oil shale in power generation in 2005 was over 90 percent. Total share of oil shale in power and heat energy generation was nearly three quarters (Figure 1).

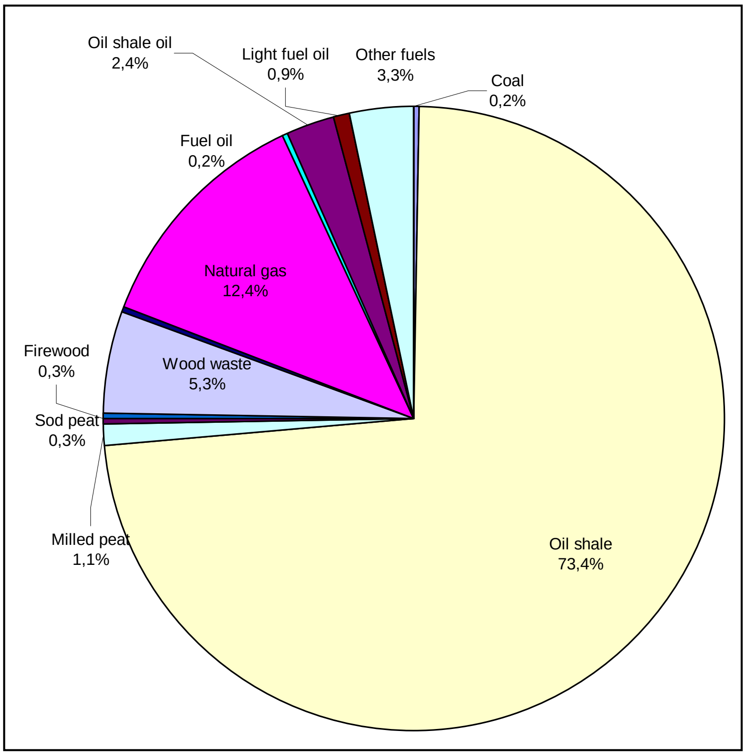

Figure 1: Fuels used for power and heat generation in Estonia in 2005

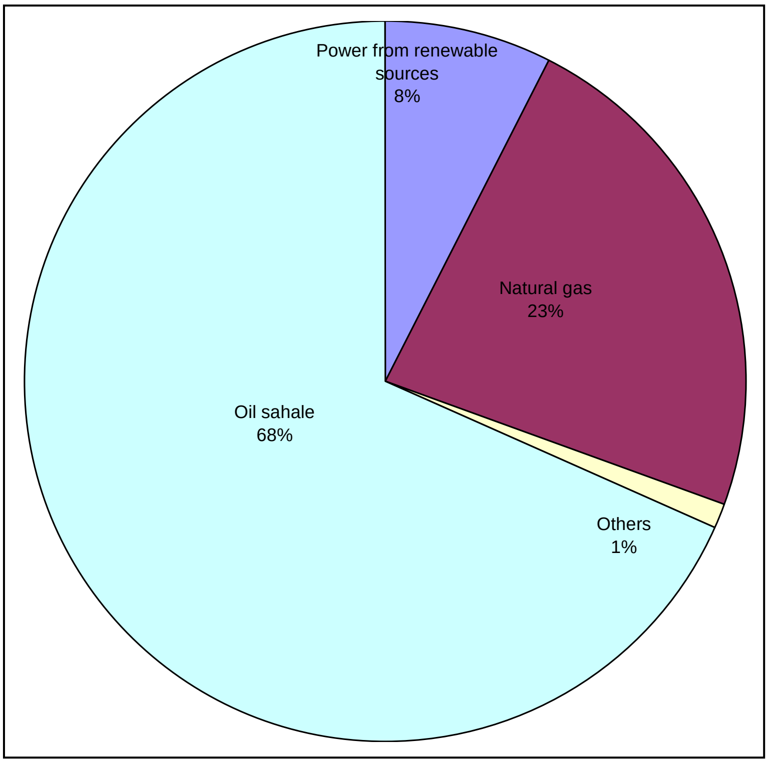

Figure 2: Predicted share of fuels for power generation in 2015

Plans for continuing oil shale industry are characterized by following principles:

1. Continuing renovation of Narva power plants, orientating on circulating fluidized bed technology.
2. Applying other technological solutions in oil shale based power industry like combustion under pressure; blending oil shale with other (including renewable) fuels; large scale production of oil shale oil and using shale oil in local power generation.
3. Radical changing of structure of Estonian energy sector, abandoning oil shale and concentrating on other mainly imported energy sources. The most possible alternatives would be natural gas and coal.

According to Directive 2003/54/EC of the European Parliament concerning common rules for the internal market in electricity, Estonia has to open its electricity market in amount of 35 per cent since 2009 and fully since 2013. That calls a challenge for oil shale based power industry to maintain competitiveness.

Table 1: Oil shale consuming industry in 2007

		Eesti Power Plant	Balti Power Plant	VKG Aidu Oil OÜ	Kiviõli Keemia-tööstuse OÜ
Field of use		electricity/oil	electricity	oil, chemistry	oil, chemistry
Quality agreed in contract **	MJ/kg	8,4	8,4	11,32	11,32
Quality agreed, in upper heating value figures ***		10,70	10,70	13,86	13,86

* Calculated, not official

** Contract states the lower heating value and limit of moisture content

*** calculated in moisture content of 12% for VKG Aidu Oil and Kiviõli Keemiatööstus and in moisture content of 10% for all other consumers

Underground mining is performed for half of Estonian oil shale mining capacity. It is done in amount of 7 million tonnes of oil shale, not including separated limestone that is 40% of mass in addition per year. Currently oil shale is mined in 2 underground mines in addition to 7 surface mining fields. The maximal number of underground mines has been 13 with total annual output of 17 million tonnes per year. Oil shale bedding depth reaches 80 meters while seam thickness is 2,8 meters. Room and pillar mining system with drilling and blasting is used today with square shape pillars left to support the roof.

For solving CO2 reducing requirement following steps have to be considered:

- Trade oil shale quality has to be increased by removing or separating limestone from the material
- Backfilling of mines has to be considered
- Technology of underground shearing has to be tested

For increasing trade oil shale quality, removing or separating limestone from the material has to be performed.

The main option used today is Heavy media separation (HMS). Other, currently being tested, is high-selective mining with surface miner. The main task for mechanical cutting is cutting selectively oil shale (15MPa) and hard limestone (up to 100MPa). The oil shale seam consists up to 50% of limestone layers and pieces. This raises a question of utilising waste rock or ash on the waste material deposit or in surface or underground mine.

Table 2: Production figures of oil shale mines in, 2004/05

	Unit	Estonia mine	Viru mine	Aidu open cast	Narva open cast
Total trade oil shale	106 t	4,71	1,91	1,93	4,73
	MJ/kg, lower	11,250	11,947	11,160	10,694
fuel oil shale	106 t	3,85	1,19	1,72	4,73
	MJ/kg, lower	10,696	10,780	10,816	10,694
concentrated oil shale	106 t	0,86	0,71	0,21	
	MJ/kg, lower	13,835	13,887	13,817	
Run-of-mine	106 t	8,34	3,05	2,65	4,73
Trade oil shale share in ROM	%	56,5%	62,5%	72,7%	100,0%
Waste rock (limestone)	106 t	3,63	1,14	0,72	0
Share of waste rock	%	43,5%	37,5%	28,3%	0,00%
Design production*	106 t	5	2	2	5

* designed production is annual possible amount of trade oil shale according to initial project concerning 60 per cent oil shale and 40 per cent waste.

It is just becoming an issue that oil shale mining and further processing in power plant or oil factory is in same sequence and optimal heating value may differ from current values. Issues are becoming more topical with raising environmental taxes. Higher heating value also results in reduced emissions of CO2 and ash.

Mining conditions

Oil shale bed in Estonia is deposited in the depth of 0…100 m with the thickness of 1,4…3,2 m in the area of 2489 km^2. The mineable seam consists of seven kukersite layers and four to six limestone interlayers. The layers are named as A…F1. The energy rating of the bed is 15…45 GJ/m^2.

The feasibility of the oil shale mining depends on energy rating, calorific value of the layers, thickness and depth of the seam, location, available mining technology, world price of competitive fuel and its transporting cost, oil shale mining and transporting cost. In addition, nature protection areas are limiting factors for mining.

The economic criterion for determining Estonia's kukersite* oil shale reserve for electricity generation is the energy rating of the seam in GJ/m^2. It is calculated as the sum of the products of thickness, calorific values and densities of all oil shale layers A-F1 and limestone interlayers. A reserve is mineable when energy rating of the block is at least 35 GJ/m^2 and sub economic if energy rating is 25…35 GJ/m^2. According to the Balance of Estonian Natural Resources, the oil shale reserve was 5 billion tonnes in the year 2000. Economic reserve was 1,5 billion t and sub economic 3,5 billion t. These figures apply to oil shale usage for electricity generation in power plants. In the case of wide-scale using of oil shale for cement or oil production, the criteria must be changed. Therefore in changing economical conditions it is important to know operating expenditures and possible revenue.

There is a question how much money will mine loose if oil shale sold is of higher calorific value than it is stated in contract. Simplified approach for that is to calculate the per cent difference of heating values and reduce profit by the same percentage. In reality, fixed and variable costs must be taken into account and the fact that in client (power plant in our case) gets more energy from oil shale tonne, the one requires less oil shale and reduces the order by respective amount or even by

* In addition to kukersite oil shale in Estonia, there are occurrences of another kind of oil shale – dictyonema argillite, mined and used in Sillamäe for extracting uranium in 1948…1953.

bigger amount of oil shale due to increased efficiency (Table 3:Example of lost money by selling oil shale of higher quality than in contract).

If a mining enterprise will sell 1 194 thousand tonnes of fuel oil shale with lower heating value of 8,4 GJ/t and 712 thousand tonnes of concentrate, the amount of losing money is presented if average heating value of sold fuel oil shale 8,6 MJ/kg. First column indicates base case.

Table 3: Example of lost money by selling oil shale of higher quality than in contract

	1.	2.	3.	Units
Lower heating value according to contract	8,4	8,6	8,6	GJ/t
Amount of fuel oil shale sold	1 193 704	1 193 704	1 167 359	T
Amount of concentrated oil shale	712 406	712 406	712 406	
Upper calorific value of fuel oil shale	10,702	10,944	10,944	GJ/t
Lower calorific value of fuel oil shale	8,4	8,6	8,6	GJ/t
Moisture content of fuel oil shale	12	12	12	%
Upper calorific value of fuel oil shale	13,887	13,887	13,887	GJ/t
Amount of energy in fuel oil shale	12,8	13,1	12,8	PJ
Amount of energy in concentrated oil shale	9,9	9,9	9,9	PJ
Cost price of trade oil shale	7,55	7,64	7,67	EUR/t
OpEx	14 396	14 568	14 431	Thousand EUR
Increase of OpEx		171	35	Thousand EUR
Less income from sale (7,81 EUR/t)			206	Thousand EUR
Total less income			241	Thousand EUR

The main interested partners for the tests could be Oil Shale Companies in Estonia, Oil producing company, Mining Department of Tallinn University of Technology, Estonia, (http://mi.ttu.ee/mining), Continuous Miner (or road header) producer, partner research group or institute working together with the machinery producer, process equipment (crusher, sizer, screen, gravity separator) producer, pump (pumps, dewatering and backfilling systems) producer, support (supporting, bolting) producer.

Fine separation is needed for enriching fine part of limestone and oil shale mixture. Possible solutions are drying, pneumatic separation, heavy media separation, water jet separation or others.

Crushing

Sizers or other types of crushers are needed for getting oil shale fraction 0-15 mm, and limestone 0-45 mm. Since fines are difficult to handle both in power plant and oil generation process, the share of 0-5mm should be minimum.

Screening

Roll screens or banana screens are required for screening of fines of oil shale material. This avoids double crushing of the sized material. It is possible, that drier should be used together with screening, crushing and storing operations.

Continuous miner

Continuous miners are needed for non-blasting operations in new potential underground oil shale mines. The main requirement is to cut hard limestone and soft oil shale with the same machine.

A longitudinal cutting head type was first introduced in the former Soviet Union by modifying the Hungarian F2 road headers and in 1970s in Estonia by modifying the Russian coal road header 4PP-3. Evaluation of breakability was performed by a method developed by A. A. Skotchinsky Institute of Mining Engineering (St Petersburg, Russia). For this purpose over a hundred samples produced by cutting of oil shale and limestone, as well as taken in mines by mechanical cutting of oil shale were analysed. In researches evaluations were made for using coal-mining equipment for mining oil shale.

Comparative evaluations were made by the experimental cutting of oil shale in both directions – along and across the bedding, including also mining scale experiments with cutting heads rotating round horizontal (transverse heads) and vertical axes (longitudinal heads). In both cases the efficiency was estimated by power requirement for cutting. The feasibility was shown of breaking oil shale by direction of cutting across the bedding by using cutting drums on horizontal axis of rotation. The research also evidenced that the existing coal shearers proved low endurance for mining oil shale. Therefore, the problem arose of developing special types of shearers for mining oil shale or modifying the existing coal shearers.

It was further stated that the better pick penetration of the longitudinal machines allows excavation of a harder strata and at higher rates with lower pick consumption for an equivalent sized transverse machine. It was reported that with the longitudinal cutting heads the dust forming per unit of time decreases due to smaller peripheral speed. The change in the magnitude of the resultant boom force reaction during a transition from arcing to lifting is relatively high for the transverse heads, depending on cutting head design. Specific energy for cutting across the bedding with longitudinal heads is 1.3–1.35 times lower which practically corresponds to the change of the factor of stratification.

The results of these tests were used in large body of fundamental research into rock and coal cutting in the (United Kingdom) UK during the 1970’s and early 1980’s at the UK Mining Research and Development Establishment.

Three decades ago a progressive mining method with continuous miner, which is most suitable for the case of high-strength limestone layers in oil-shale bed, did not exist in oil-shale mines of the former USSR and in Estonia. Therefore, up to now oil shale mining with blasting is used as a basic mining method in Estonia minefields while continuous miner was tested for roadway driving only. With regard to cutting, the installed power of coal shearers and continuous miners has increased enormously since the original work. Actual state of the market has changed and a wide range of powerful mining equipment from well-known manufacturers like DOSCO, EIMCO, EICKHOFF, etc. is available now.

We have 30 years of experience in cutting with longwall shearers which were not capable of cutting hardest limestone layer inside of the seam. Tests with road headers have been carried out in 1970ties.

We have tested Wirtgen surface miner SM2100 and SM2600 for two years and SM2200 and Man Tackraf surface miner, and are currently testing Wirtgen surface miner SM2500 for high selective mining in an open cast mine.

Due to horizontal lying of layers, cutting faces parallel or inclined shearing forces when using rotating cutting heads in the seam (Figure 3:Oil shale cutting principles).

In the case of longwall cutting scheme that was used in Estonian oil shale mines (Sompa, Ahtme, Kohtla, Tammiku) the cutting head situated in the middle of the seam, allowing cutting tools to cut layers perpendicularly. As shown in upper drawing main cutting is performed in "green zone" that requires less energy and consumption of cutting tools is low (upper drawing Figure 3).

The other scheme, currently tested high selective shearing with surface miner works with the same principle, using advantage of cutting in direction of free surface (middle drawing Figure 3).

The third option that is not tested, is working in "red zone" cutting toward parallel shearing force, requiring presumably most energy and the consumption of cutting tools is highest (lower drawing Figure 3).

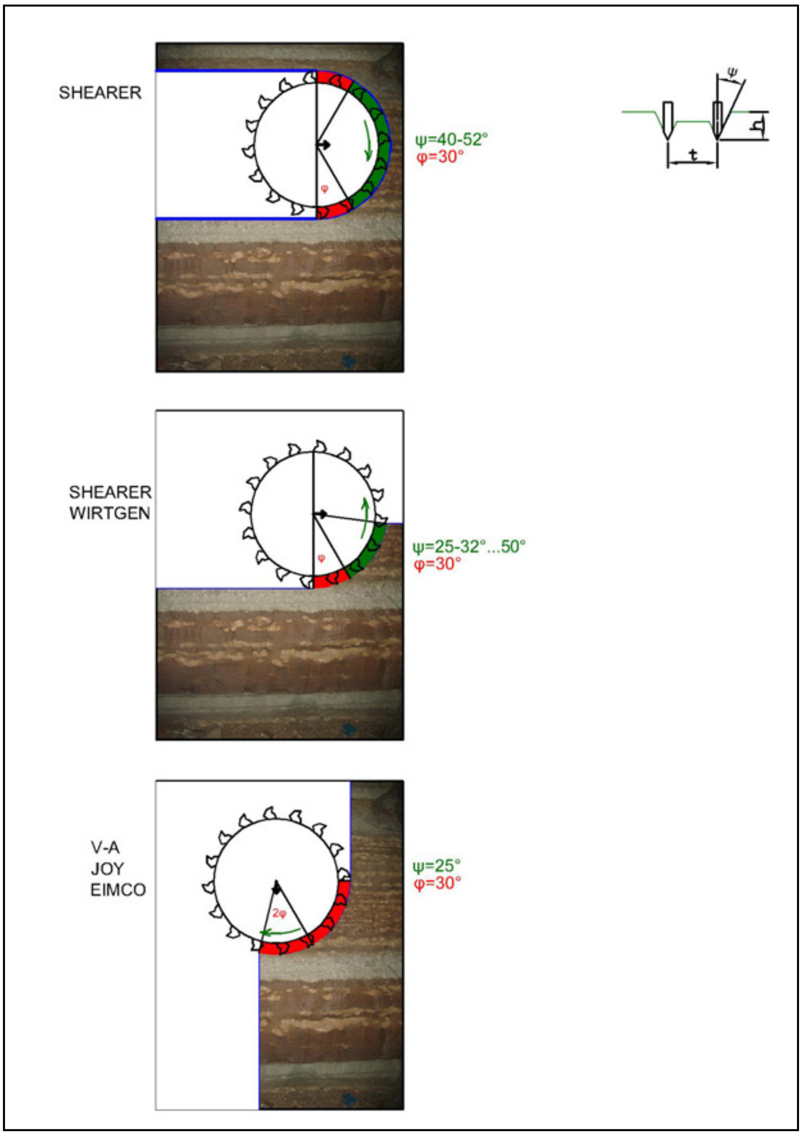

Figure 3: Oil shale cutting principles 1-3

In case of vertical shearing, horizontally placed cutting cylinder is not forcing any parallel shearing opposition and should be most effective way. The problem is that there are no suitable continuous miners on the market at the moment (upper drawing Figure 4:Oil shale cutting principles).

Fifth option is using cylinder with cutting tool that are situated both in top and the perimeter of the cylinder. It meets mainly "red zone" forces (lower drawing Figure 4). In the third option that is not tested, is working in "red zone" cutting toward parallel shearing force, requiring presumably most energy and the consumption of cutting tools is highest (lower drawing Figure 3).

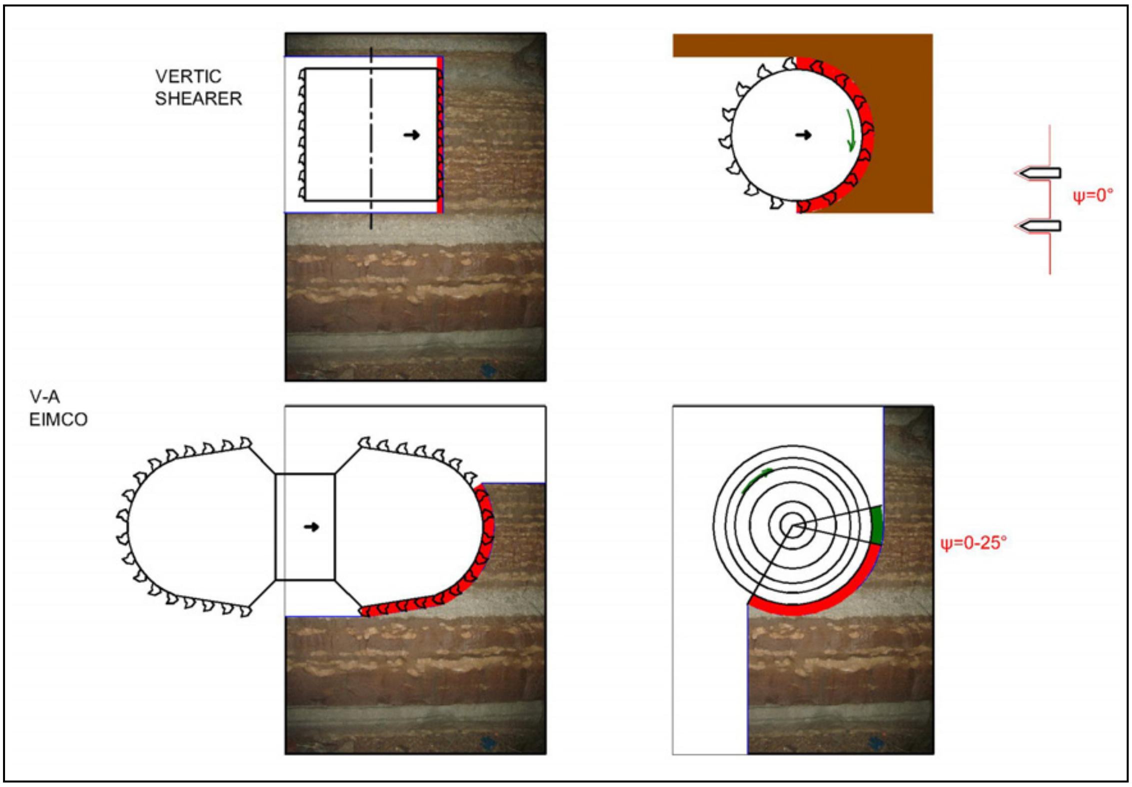

Figure 4: Oil shale cutting principles 4-5

Conclusions

Three main steps of developing Estonian mining have to be completed in order to normalise resource usage: Separating limestone from oil shale; Backfilling waste material into mine and short wall mines has be tested in order to mine in underground in wetland areas. Previous test with shortfall, longwall, and surface mining have shown good results. Additionally fine separation has to be tested.

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