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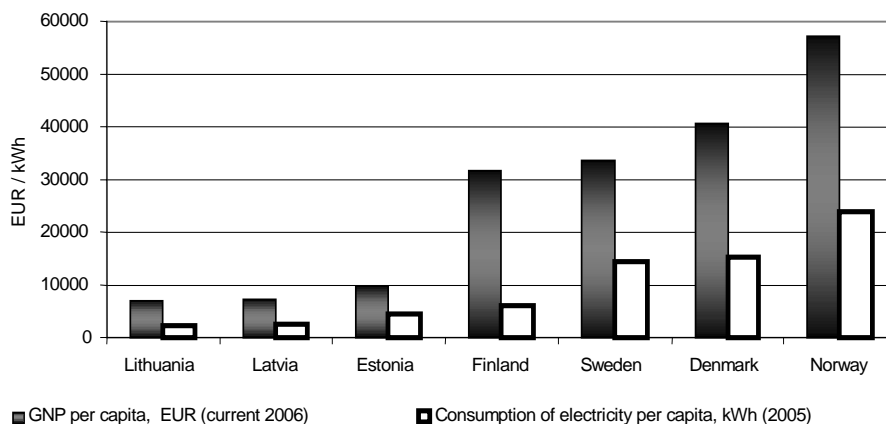
Fig. 1. GNP per capita (current prices 2006) and consumption of electricity by industry, transport activities and households/services in 2005 according to Eurostat [4].

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.
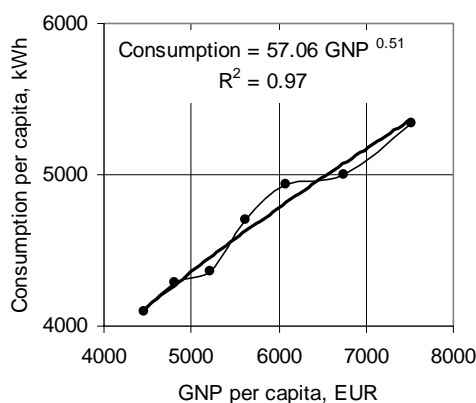

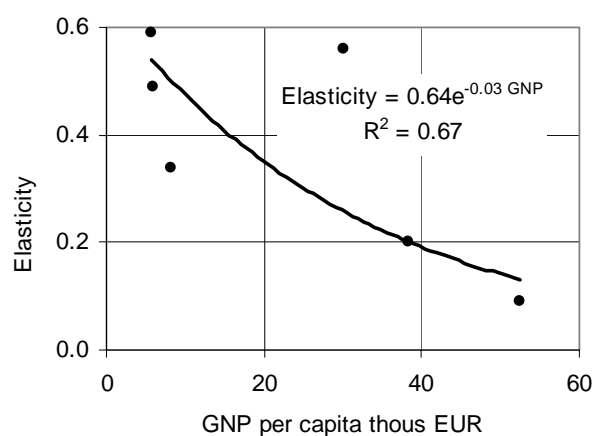*Fig. 2.* Dependence between electricity consumption and GNP per capita.

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.
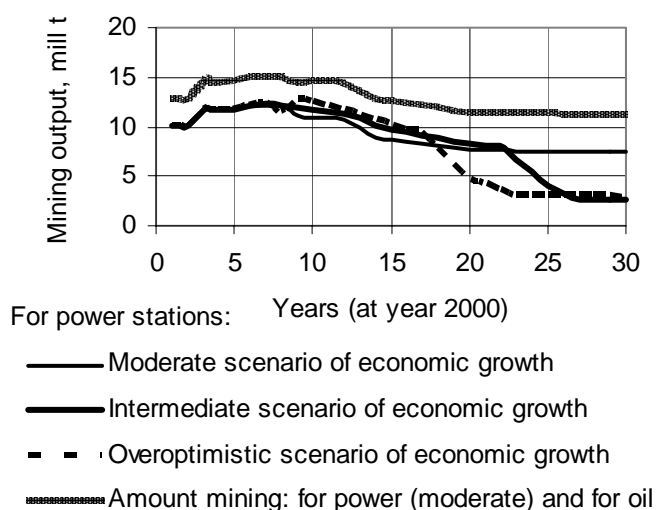

Fig. 4. Forecast oil shale mining output according to economic growth scenarios.

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.
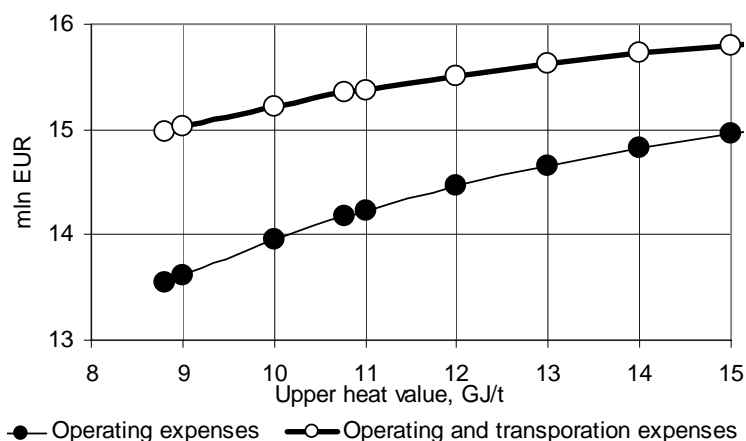

Fig. 5. Relation between upper heat value and expenses for mine giving total energy amount of 22.8 PJ.
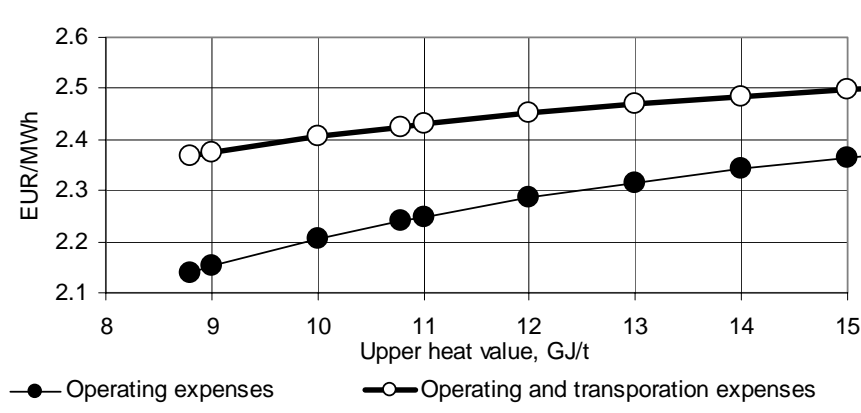
Fig. 6. Relation between energy cost and heat value in mine giving total energy amount of 22.8 PJ.
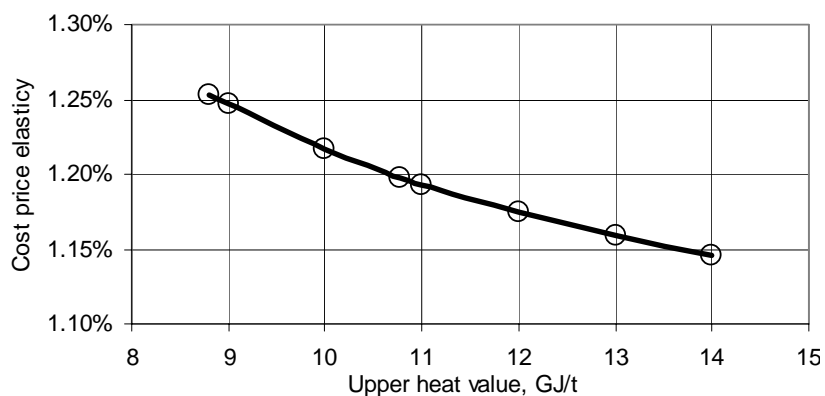

Fig. 7. Increase of cost price with one per cent rise of heat value of oil shale.

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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