Oil Shale, 2003, Vol. 20, No. 3 SPECIAL
pp. 388-397
ISSN 0208-189X

SUSTAINABILITY OF OIL SHALE-BASED ELECTRICITY PRODUCTION

K. TENNO*, A. LAUR**

Estonian Institute of Economics
at Tallinn Technical University
7 Estonia Blvd., Tallinn 10143, Estonia

Production of oil shale-based electricity covers Estonian electricity consumption and enables also to export electricity. Oil shale-based electricity production is by now competitive on the electricity market of the Baltic States and of the neighboring EU Member States. However, production of oil shale-based electricity has low energy efficiency, demands large investments for renovation and has high environmental risks. Taxation of environmental damage will be more severe in the future, lowering the competitiveness of oil shale-based electricity. Therefore, the key issue of sustainable development of Estonian energy sector is reduction of the environmental damage of the oil shale-based electricity production, or reduction of the share of oil shale in the energy balance at the expense of other energy resources, especially renewable energy.

Introduction

A characteristic of the Estonian energy sector is production of electricity from local fuel – oil shale. The Estonian oil shale-based energy complex was founded during the Soviet period ensuing from demand for electricity in the north-western region of the former Soviet Union. Intensive development of this complex started in the 1950s. Oil-shale mines and quarries were established and two large power plants (Baltic and Estonian PPs), and several smaller oil-shale ones were built, which enabled in the 1980s to extract 25-30 million tonnes of oil shale and produce electricity in the amount of 17-19 TWh, from which 50-60 % was exported to other north-western regions of the Soviet Union. Today Baltic and Estonian PPs are business units of the power generation company *Narva Elektrijaamad AS* (*Narva Power Plants*).

After regaining independence, the oil-shale energy complex inherited from the Soviet period no more satisfied the conditions of Estonian economy and principles of sustainable development. It is remarkable overcapacity that worsens the operating efficiency of the complex. The plants are old, need

* Corresponding author: e-mail *koidut@tami.ee*
** e-mail *antonl@tami.ee*

large investments for renovation, oil shale-based electricity production is extremely polluting and water consuming. Therefore, the long-term energy sector development plan [1] adopted by the *Riigikogu* (Estonian Parliament) in 1998 has envisaged gradual reduction of the share of oil shale-based electricity. However, oil shale is still dominating in electricity production, having dropped from 98 % in 1996 to 90 % in 2001.

In 2001, *Narva Power Plants* started to renovate two 200-MW energy blocks using a new, circulating fluidized-bed combustion (CFBC) technology [2]. The new technology is expected to be more effective and have less negative impact on the environment (lower SO_2 and CO_2 emissions) compared with the so far used pulverized combustion technology. Therefore it is important to analyze competitiveness of alternative electricity productions in Estonia in comparison with oil shale-based electricity productions. The key issue here is consideration of the environmental impacts and the respective costs.

Comparison of Energy Sector Developments in Estonia and in EU-15, CC-10 and Neighboring Countries

The purpose of this analysis is to compare quantitatively the main indicators of the Estonian energy sector with the respective statistics of the EU Member States (EU-15), Candidate Countries (CC-10) and also some neighboring countries (Nordic countries and other Baltic States). The OECD approaches to measuring sustainable development [3, 4] have been taken into consideration in the analysis.

The indicators analyzed are total primary energy supply (TPES) and electricity consumption (EC) per capita. We make also comparisons of CO_2 emissions (per capita) from fossil fuel combustion. The main attention is paid to the indicators characterizing the energy sector efficiency – first and foremost the gross domestic product (GDP) energy intensity (TPES per unit of GDP) and also the GDP electricity and CO_2 intensity. For analysis of these energy-related indicators, data of the International Energy Agency (IEA) have been used – latest available data are from 2000 (Table 1).

Comparison of the TPES per capita in EU Member States and Candidate Countries indicates that differences are remarkable: the weighted averages are 3.86 t oe and 2.64 t oe per capita, respectively. In Estonia, the primary energy consumption per capita is relatively high (3.30 t oe). Due to the low level of Estonian GDP, also the GDP (PPP)* energy intensity is high (0.38 kg oe/USD'95) in Estonia, exceeding the average of the EU Member States (0.18 kg oe/USD'95) more than 2 times and is also higher than the average of the Candidate Countries (0.26 kg oe/USD'95). At the same time, a positive trend is the declining GDP energy intensity in Estonia – decline in the period 1993–2000 has been 2.1 times [5].

* PPP (purchasing power parity) expresses the real purchasing power of national currency eliminating to some extent the differences of price levels between the countries.

Table 1. **Comparative Data of the Main Energy-Related Indicators, 2000**[*]

Countries	Per capita			Per GDP (PPP), USD'95		
	TPES, t oe	EC, kWh	CO_2, t	TPES/GDP, kg oe	EC/GDP, kWh	CO_2/GDP, kg
EU-15 average	3.86	6547	8.35	0.18	0.30	0.38
Denmark	3.64	6481	9.38	0.14	0.25	0.37
Finland	6.40	15274	10.58	0.27	0.64	0.44
Sweden	5.35	15661	5.86	0.23	0.68	0.26
Norway	5.71	25187	7.48	0.22	0.96	0.28
CC-10 average	2.64	3725	7.47	0.26	0.37	0.74
Latvia	1.54	2080	2.76	0.23	0.31	0.42
Lithuania	1.92	2381	3.03	0.29	0.32	0.46
Estonia	3.30	4628	10.21	0.38	0.53	1.17

[*] Source: http://www.iea.org/statist/keyworld2002/key2002/keystats.htm

Electricity consumption per capita is also high in Estonia (see Table 1) – 4628 kWh in 2000 (according to the IEA method of calculation, the gross inland electricity consumption is used here – the own use by power plants is included). This is 1.2 times more than the average electricity consumption per capita in Candidate Countries, but still significantly smaller than in the EU Member States (only 71 % of the EU average level). Resulting from the low GDP (PPP) level, the situation is opposite for the electricity consumption per unit of GDP (PPP) – compared with EU Member States, electricity consumption in Estonia was 1.8 times higher, or in other words – Estonia spent 1.8 times more electricity for producing one GDP (PPP) unit in 2000.

Oil shale-based electricity production is a very big source of greenhouse gases, primarily CO_2, which causes a global climate change impact. CO_2 emission per capita, considering the small number of population in Estonia, is one of the highest both among the Nordic countries (except Finland) and compared with EU Member States. Still, CO_2 emission per capita has been decreasing constantly in Estonia. In 1990, the Estonian indicator surpassed the EU average level by 2.6 times [6], in 2000 – by 1.2 times (see Table 1).

The abatement of the Estonian indicator was much faster than in the EU Member States where it was either stable or even rose. If to look at the CO_2 emission per unit of GDP (PPP) in Estonia (GDP CO_2 intensity), it is still in 2000 about 3 times higher than the EU average, 4.5 times higher than in Sweden and Norway, or 3.2 times higher than in Denmark. This is primarily due to the small GDP in Estonia, because CO_2 emission, as mentioned above, has diminished considerably. This is illustrated also by the relatively high CO_2/GDP values of our closest neighbors (Latvia, Lithuania) and other EU Candidate Countries, where the GDP level is also low compared with EU Member States.

Estonian Electricity Sector Developments in 1990–2001

Production and consumption of oil shale-based electricity – the main output of Estonian energy sector – has been decreasing since 1990. The decline has been due to the general structural changes in the economy combined with the decline of industrial and agricultural production in Estonia and the fall of electricity exports. Electricity consumption in Estonia has diminished nearly 1.3 times and exports more than 7 times in the period 1990–2001. Analysis of the dynamics of final inland consumption of electricity (Fig. 1) indicates that the sharp falling tendency in the initial years of transition began to be replaced by stabilization of consumption only in 1994. Since 1996, the consumption of electricity has increased slightly. This dynamics is consistent with the general economic decline or growth in Estonia in the years under study [6].

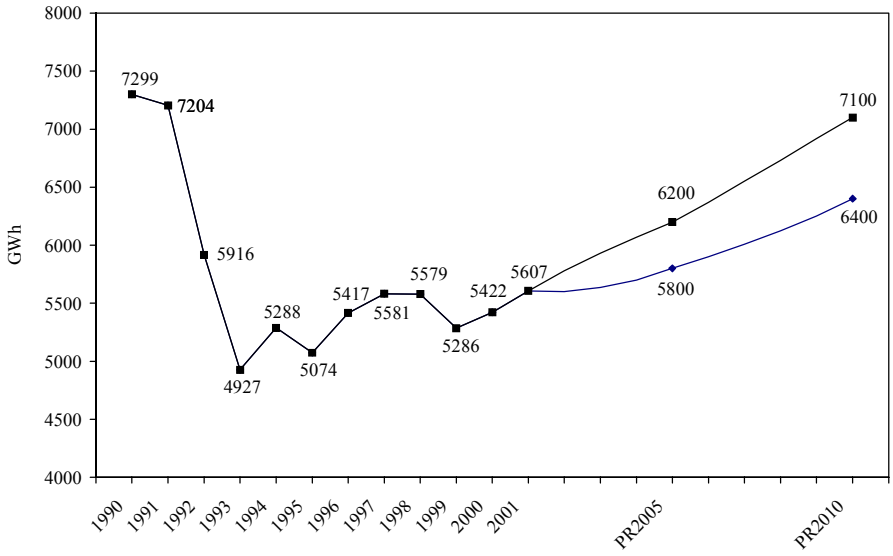

Fig. 1. Dynamics and forecast of electricity final consumption in Estonia: ■ high, ◆ low

By 2002 the annual electricity net production has stabilized around 7500–8000 GWh and final inland consumption on the level of 5500 GWh. A more detailed analysis of the dynamics of electricity consumption by branches of economy allows us to state that this also reflects quite well the respective structural changes and development tendencies. A stabilization of electricity consumption can be perceived in industry, construction and transport in the middle of the period. Reflecting the growth of the share of business and public sector, electricity consumption by this sector also has a tendency to grow.

Electricity consumption by households reached the lowest rate in 1995, followed by a considerable growth until the end of the period (both in absolute terms and per capita). Eventually, the consumption by households in the

last years of the period, in 1998–2001, exceeded the initial level of the transition period. Considering that electricity consumption by households is regarded as one of the life quality (standard of living) indicators, such development in our energy sector must be deemed positive.

Based on the dynamics in 1990–2001, the interval forecast of the final inland electricity consumption in Estonia is calculated for 2005 and 2010. This calculation is based both on the extrapolation methods and on expert opinions on the elasticity of electricity consumption compared to GDP growth. The results of the forecast are presented in Fig. 1. It is prognosticated that electricity consumption may increase to 5800–6200 GWh by 2005 and to 6400–7100 GWh by 2010. Based on electricity demand, we have also prognosticated electricity production outputs. The estimated total demand for electricity (gross output) will be 8500–9000 GWh in 2005 and 9000–10000 GWh in 2010.

The efficiency of the Estonian electricity sector does not satisfy the principles of sustainable development and needs improvement. The shares of energy system losses and own use of power plants are high both in the gross production and electricity sales. And these indicators have worsened compared with the early 1990s (the respective dynamics are presented in Fig. 2). This can be explained by the decline in electricity production and the ensuing worse consumption of capacities. The shortcomings in reforming the Estonian energy system have also contributed to the decline in efficiency.

Table 2 presents the changes in the use of energy resources for electricity generation during the period 1997–2001. One can see that the share of oil shale dominating in power generation in Estonia has declined from 95.3 % in 1997 to 90 % in 2001. This reduction happened mainly at the expense of increased use of natural gas, while the use of other fuels remained at the level of 1997. The share of electricity produced from renewable energy sources remained only around 0.1 % in 2001. In 2002, the latter reached 0.3%.

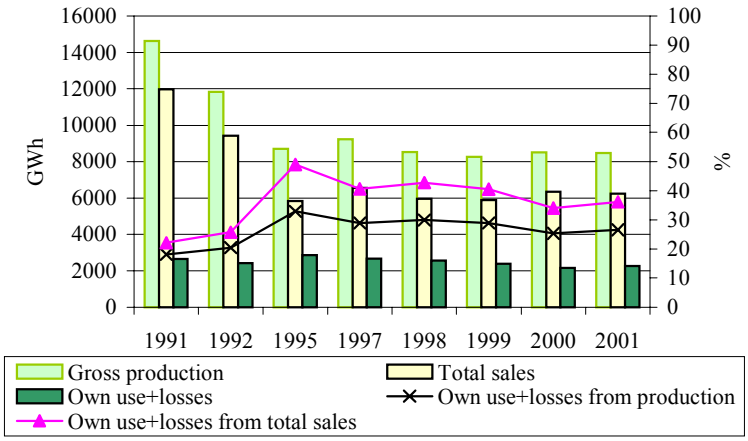

Fig. 2. Electricity balance and share of losses

Table 2. **Consumption of Energy Resources for Electricity Production***

Indicator	1997	1998	1999	2000	2001
Electricity gross production, GWh	9218	8521	8268	8513	8483
Share of oil shale-based electricity, %	95.7	93.9	93.1	91.1	90.5
Including:					
electricity from oil shale	95.3	93.5	92.3	90.7	90.0
electricity from shale oil	0.4	0.4	0.8	0.4	0.5
Natural gas consumption, mill. m^3	21	26	34	89	91
Increase, %	1.3	+24	+31	+162	+2.2
Share of natural gas in electricity production, %		2.0	2.6	6.6	6.7
Consumption of other fuels, TJ	2431	3041	3079	2324	2698
Increase, %	3.4	+25	+1.2	–25	+16
Share of other fuels in electricity production, %		4.5	5.1	2.7	3.2
Electricity production from hydro- and wind energy, GWh	3	5	5	6	8
Including:					
hydroenergy, GWh	2.95	4.70	4.68	5.67	7.72
wind energy, GWh	0.05	0.30	0.32	0.33	0.28
Share of hydro- and wind energy, %	–	–	–	–	0.1

* Source: Energy Balance 1997–2001. Statistical Office of Estonia. Tallinn, 1998–2002.

Figure 3 gives a comparison of the development trends of the basic tariff for households and the consumer price index (CPI) in the period 1993–2002 (CPI is used as the main indicator of inflation in Estonia). One can see that until 2001 the basic tariff for households has risen less than inflation, but after the recent price rises (01.01.2001 and 01.04.2002) anticipating inflation. The real growth of the basic tariff for households has been 1.1-fold during the whole period.

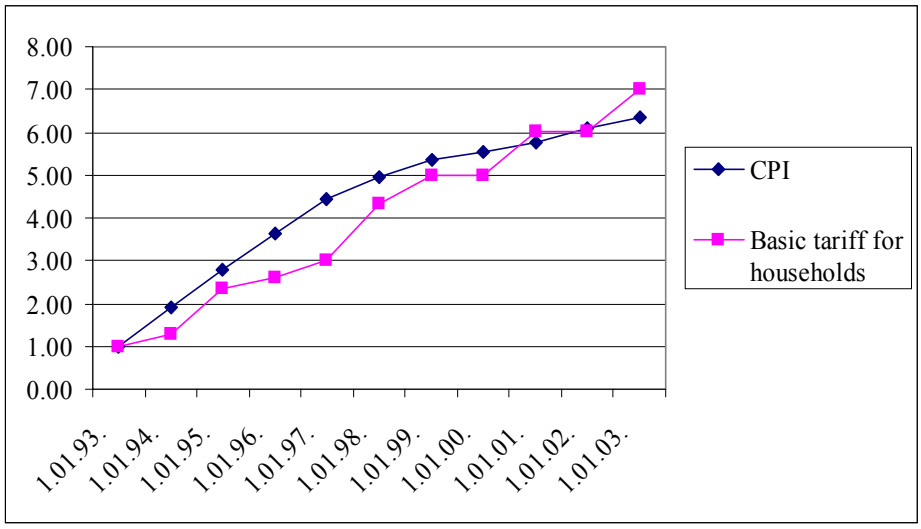

Fig. 3. Development trends of the basic tariff for households and consumer price index in 1993–2002

Analysis and Forecast of the Oil Shale-Based Electricity Cost Price

Analysis and prognostication of the oil shale-based electricity cost price (production price) are based on data provided by the annual reports of the power company *Eesti Energia AS* (*Estonian Energy*) for the financial years 2000/2001 and 2001/2002 [7, 8] and also by environmental reports of *Estonian Energy* for 2000 and 2001 [9, 10]. We have analyzed formation of the oil shale-based electricity cost price at *Narva Power Plants* in 2001. Special focus is on the role of environmental costs in the price. We also have prognosticated the oil shale-based electricity cost price for 2005 and 2010 taking into account the requirements of the Estonian Environment Strategy and the Directive of the European Parliament and of the Council on the limitation of emissions of certain air pollutants from large combustion plants (2001/80/EC) [11]. The latter set limitations to the net production of *Narva Power Plants* – up to 6600 GWh after 2005 and 5340 GWh after 2008.

Prognostications of the electricity cost price are based on analysis of previous years' data and expert opinions. For example, the main growth factor of labor costs, as we see it, is the impact of inflation (growth of CPI), but on the other hand, growth of labor efficiency. Prognostications of pollution charges for 2005 are based on the rates established in the Pollution Charge Act Amendment Act [12]. For 2010, there are two variants of prognosis. Under the first variant (low) the pollution charge and resource tax growth rates have been proposed based on the Estonian environment policy so far. For example, the CO_2 tax rate will be 30 kroons/t (according to the Pollution Charge Act Amendment Act it will be 11.3 kroons/t in 2005). We have also taken into consideration rise in efficiency and potential reduction of pollution emissions as a result of technological reconstruction of *Narva Power Plants*.

Under the second variant (high) for the year 2010 we have experimentally based our prognostications on the CO_2 tax rates proposed by the European Union already in the mid-1990s – 10 USD per oil barrel equivalent [13], which with the present exchange rate of the US dollar equals approximately 300 kroons per tonne of CO_2. However, our prognosis still takes into account only half of this rate – 150 kroons/t. This is a very high rate for Estonia, though many EU countries (for instance developed Nordic countries Denmark and Sweden) use already today much higher CO_2 tax rates [14].

Calculation results (Table 3) indicate that the oil shale-based electricity cost price in *Narva Power Plants* was 38 sents/kWh or 2.4 EUR/100 kWh according to the 2001/2002 financial year report [8], from which 15.8 % are environmental costs. The environmental costs and their proportion will increase in the future. The oil shale-based electricity cost price for the year 2005 will be 46 sents/kWh or 3 EUR/100 kWh, where the environmental costs will account for 17.4 %.

Table 3. **The Oil Shale-Based Electricity Cost Price and Forecasts**

Cost items	2001, actual		Forecasts					
	sent/kWh	%	2005		2010			
					Low environmental costs		High environmental costs	
			sent/kWh	%	sent/kWh	%	sent/kWh	%
Materials, consumables and supplies	25.8	68.1	29.2	63.1	33.5	54.1	33.5	43.7
Including resource payments	1.3	3.5	1.5	3.2	2.4	3.9	2.4	3.1
Operating expenses	6.8	18.0	8.9	19.2	14.9	24.0	29.6	38.6
Including environmental costs	4.2	11.2	6.0	13.0	11.0	17.7	25.7	33.6
Personnel expenses	11.8	31.2	14.8	32.0	20.8	33.6	20.8	27.1
Other expenses	0.2	0.4	0.2	0.4	0.2	0.3	0.2	0.3
Depreciation	6.6	17.4	7.6	16.4	10.5	17.0	10.5	13.7
Total costs	51.2	135.0	60.7	131.1	79.9	129.1	94.6	123.5
Sales of by-products	–13.2	–35.0	–14.4	–31.1	–18.0	–29.1	–18.0	–23.4
Total oil shale-based electricity production costs	38.0	100.0	46.3	100.0	61.9	100.0	76.6	100.0
Net production, GWh	6596		6430		5300		5300	
Cost price:								
sent/kWh	38	100.0	46	100.0	62	100.0	77	100.0
EUR/100 kWh	2.4		3		4		4.9	
Including environmental costs								
sent/kWh	6	15.8	8	17.4	13	21.0	28	36.4
EUR/100 kWh	0.4		0.5		0.8		1.8	

In 2010, with the lower version of environmental costs the oil shale-based electricity cost price may rise to 62 sents/kWh or 4 EUR/100 kWh, and with the higher version of environmental costs to 77 sents/kWh (4.9 EUR/100 kWh). The share of environmental costs in 2010 will grow as high as 21 and 36.4 %, respectively.

Conclusions

Oil shale currently accounts for 90 % of the energy resources used for electricity generation in Estonia. Oil shale is used in Narva Power Plants (3000 MW) and several smaller power plants, which fully satisfy Estonia's demand for electricity. Unfortunately, oil shale-based power generation has relatively low efficiency and high environmental risks. Especially large is the emission of greenhouse gases, particularly CO_2, in oil shale combustion. Mainly for environmental purposes, the national fuel and energy sector development plan (1998) envisages reduction of the proportion of oil shale-based power engineering, primarily at the expense of natural gas and renewable resources. Until now, this reduction has occurred more slowly than expected because the renewable energy is regarded too costly.

In this paper we have evaluated the share of environmental costs in oil shale-based electricity cost price in output of power plants today (2001/2002 financial year). We also tried to prognosticate the growth of these costs in the next decade (2005, 2010) depending on the environmental and energy policy developments. In 2001, environmental costs accounted for nearly 16 % of the oil shale-based electricity cost price, but if the so far relatively conservative environmental policy will continue, which serves as the basis for this research, this share may rise to 21 % or even more than one-third (36 %) by 2010. In the event of a more radical environment and energy policy, especially if the CO_2 pollution charge will approach faster the regulations in many EU countries, the competitiveness of oil shale-based electricity may considerably decline in comparison with the use of natural gas and renewable energy. Consequently, the key issue of sustainable development of oil shale-based energy is reducing of the environmental impacts primarily by using new, more environment-friendly technologies.

Acknowledgements

Authors are grateful for financial support from the Estonian Ministry of Education (Project 0341764s01) and from the Estonian Science Foundation (Grant 4793).

REFERENCES

1. Long-term national development plan for the fuel and energy sector // Riigi Teataja (State Gazette). 1998. Vol. I, No. 19, 295.
2. *Ots, A.* Oil shale combustion technology and carbon dioxide emission // Possible Energy Sector Trends in Estonia. Context of Climate Change / T. Kallaste, O. Liik and A. Ots (eds.). Tallinn: SEI-Tallinn Centre.
3. Frameworks to Measure Sustainable Development. Proc. 2nd OECD Expert Workshop in Paris 2-3 Sept. 1999. – Paris : OECD, 2000.
4. *Unander, F., Schipper, L.* IEA Energy / Emission Indicators // Frameworks to Measure Sustainable Development. Proc. 2nd OECD Expert Workshop in Paris 2-3 Sept. 1999. Paris : OECD, 2000. P. 137–149.
5. *Tenno, K.* Key features of economic development // Estonian Energy 1991–2000. Tallinn : Ministry of Economic Affairs, 2001. P. 7–13.
6. *Laur, A., Soosaar, S., Tenno, K.* Utilisation of Estonian energy resources: Towards Sustainability // Factors of Convergence: A Collection for the Analysis of Estonian Socio-Economic and Institutional Evolution / Ü. Ennuste and L. Wilder (eds.). Tallinn : Institute of Economics at Tallinn Technical University, 2001. P. 193–226.
7. Annual Report 2000/2001. – Tallinn : *Eesti Energia AS*, 2001.
8. Annual Report 2001/2002. – Tallinn : *Eesti Energia AS*, 2002.
9. Environmental Report 2000. – Tallinn : *Eesti Energia AS*, 2001.
10. Environmental Report 2001. – Tallinn : *Eesti Energia AS*, 2002.
11. Directive of the European Parliament and of the Council on the limitation of emissions of certain pollutants into the air from large combustion plants (2001/80/EC), 23.10.2001.
12. Pollution Charge Act Amendment Act // Riigi Teataja (State Gazette). 2001. Vol. I, No. 102, 667.
13. ExternE, externalities of Energy. Vol. 1: Summary by ETSU, UK, EUR 16520 EN, European Commission Directorate General XII, Brussels-Luxembourg, 1995.
14. Database on environmental taxes. 2001 (http://europa.eu.int/comm/environment/enveco/).