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Life Cycle Analysis of the Estonian Oil Shale Industry

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Introduction

Estonia is a typical post-socialist country with an inefficient energy sector, based, uniquely in the world, on oil shale mining and burning. However, as 1990 was the base year in the Kyoto Protocol, this means that Estonia is an exemplary country, which has already met its obligation to reduce CO_2 emissions by 8 % by 2008-2012 in comparison with 1990. CO_2 emissions had already decreased more than 40% by 1994 due to the restructuring of the economy and the end of electricity export to Russia. Oil shale power stations are currently selling “hot air”, and the oil shale industry is thriving due to the low resource- and environmental taxes for the oil shale industry in Estonia. Energy policies are discussed in these, advantageous for oil shale industry, circumstances in Estonia. Needless to say, oil shale as a source of energy will be the first choice for Estonian politicians also in the future.

An attempt to carry out a comprehensive Life Cycle Analysis of the oil shale industry in Estonia is presented in this paper. It should be noted that the task undertaken was complicated because, despite the seeming abundance of data, some important pieces of information were not available, even if specifically requested. However, the authors did their best, and to their best knowledge, this is the first attempt of its kind in Estonia.

It is of utmost importance which international and EU policies will prevail in the post-Kyoto period. Our understanding is that, taking into account the threat of climate change, we need to introduce ecological economic mechanisms for the full control of carbon flows at the international and national levels. This assumes the introduction of full carbon accounting in addition to the economic accounting, also on the national economy level. If this paper could facilitate the introduction of full material (carbon) flow analysis into the national accounting systems, the authors would consider their long-term aim to be fulfilled.

1. General characteristics of the energy sector in Estonia

1.1. Estonia's energy sector and its comparison with the other European countries

The balance sheet of primary energy in Estonia in 2003 is presented in Fig. 1. In 2003 the total production of primary energy in Estonia was 160 PJ, the supply of primary energy was 211 PJ (Fig.1), the gross inland consumption was 286 PJ (36% for electricity generation, 15% for heat generation, 11% for conversion to other forms of fuels and 38% is final consumption) [Energy balance 2003].

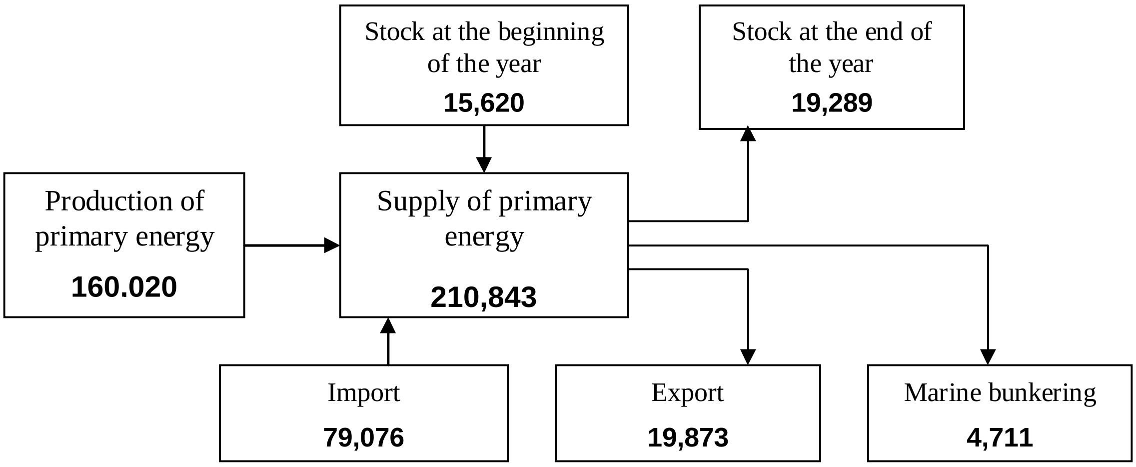


Figure 1. Balance sheet of primary energy in Estonia in 2003, TJ [Energy balance 2003].

In terms of the Total Primary Energy Supply (TPES) calculated as "production + + import – export–international marine bunkering" Estonia is close to the EU average - TPES per capita in Estonia and the average TPES in the European Union differ by 0.42 toe[1] (about 10%). However, the difference between Estonian carbon emission per TPES and the European average is remarkable – 3.31 tCO_2 against 2.22 tCO_2 per toe, i.e., emissions in Estonia are 1.6 times higher than the EU average (Fig. 2).

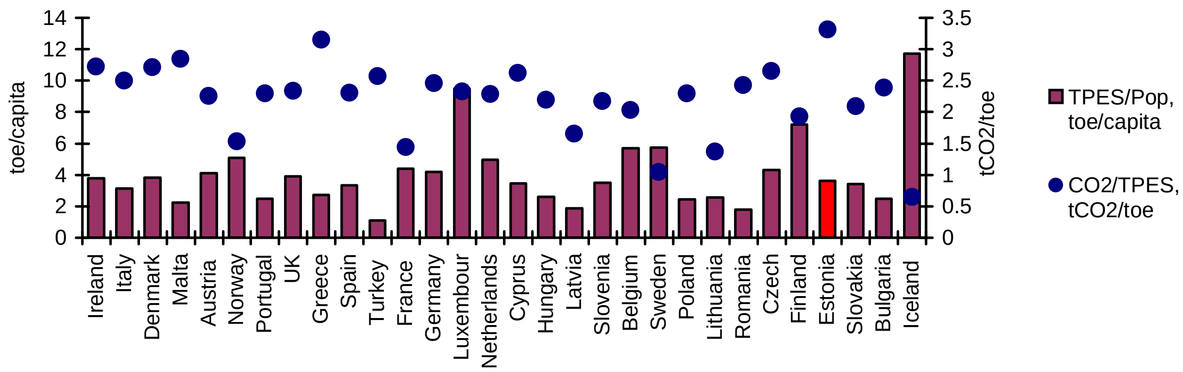


Figure 2. TPES per capita and CO_2 emission per TPES by countries of European Union and some other countries, 2003 [Key world energy statistics 2005].

The high CO_2 emission per TPES (Fig. 2) is mainly due to the use of oil shale for electricity and heat generation, which has a (very) low overall energy generation efficiency.

[1]Tonne oil equivalent

The major source of primary energy during the last 40 years in Estonia has been oil shale (Fig. 3). More than 80% of the internal supply of primary energy is currently provided by oil shale. However, as seen from Figure 3, the share of oil shale in the internal supply of primary energy was greater than 90% between 1970 and 1990. In 1980, almost 30 million tonnes of oil shale was extracted and used – this was the absolute peak for the industry. In the 1990ies oil shale extraction dropped because a nuclear power station was constructed in Sosnovyj Bor near St. Petersburg, and in 1990 (the base year of the Kyoto Protocol) 21 million tonnes were extracted. After Estonia regained her independence, the use of oil shale decreased further, stabilizing currently at 12-14 million tonnes annually.

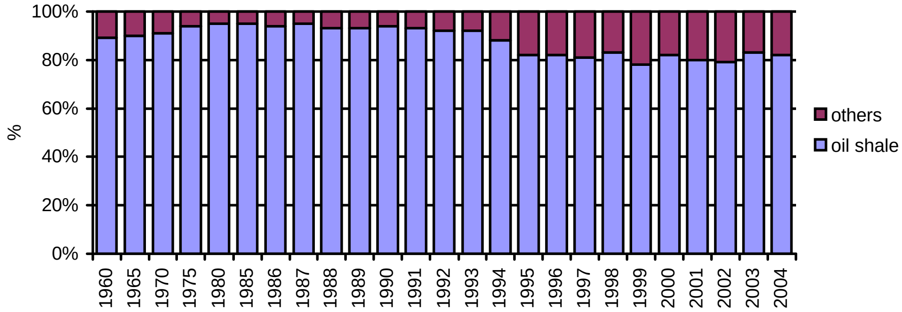


Figure 3. The structure of production of primary energy in Estonia, % [www.stat.ee]

Oil shale is consumed for electricity generation (72% of oil shale extracted) and as raw material for the chemical industry (almost exclusively shale oil - 22%). 6% of the oil shale extracted is used for heat generation [Energy balance 2003]. More than 90% of electricity is produced from oil shale (Fig. 4). Almost all electricity (97%) is produced by “AS Eesti Energia”- a state owned vertical energy monopoly (see also Chapter 4.2).

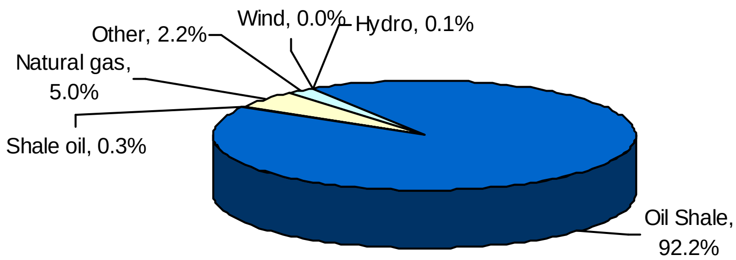


Figure 4. The resources for electricity generation in 2003 [Estonian electricity sector…, 2004].

However, only 20% of the final energy consumed is produced from oil shale in Estonia – mainly electricity (18% of the total final consumption), and the remaining 2-3% for heat and for the production of cement (1%) (Fig. 5).

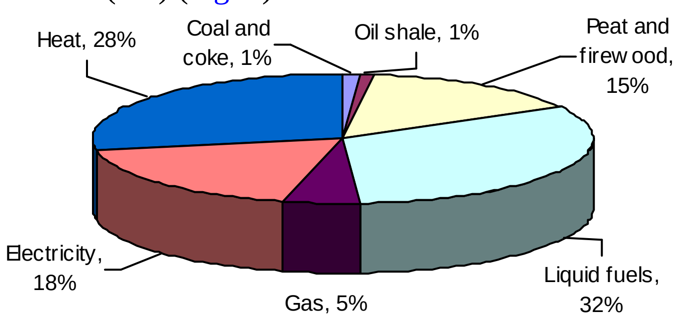


Figure 5. The structure of final energy consumption in Estonia in 2003 [Energy balance 2003].

The GDP of Estonia is 4.852 thousand USD per capita, which is 3.4 times lower than the average of the selected European countries (16.5 thousand dollars per capita) – see Fig. 6. The electricity consumption in Estonia was 5,226 kWh per capita against the European average of 7,654 kWh per capita. The emission of CO_2 in Estonia was 12.04 tonnes per capita, which was 3.6 tonnes of CO_2 more than the average of the selected countries (Fig. 6).

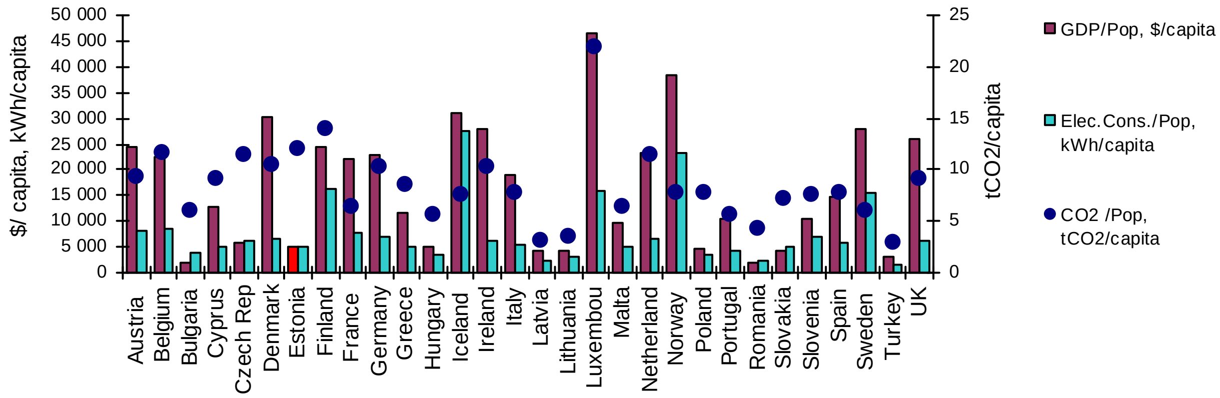


Figure 6. GDP, Electricity consumption and CO_2 emission per capita in 2003 [Key world energy statistics 2005].

As seen from Fig. 7, the CO_2 emission per GDP (PPP)[2] of Estonia – carbon intensity – is 2.8 and 2.2 times higher than the European average, respectively. Estonian CO_2 emission is 4.4 times higher than CO_2 emission per GDP in Finland and almost 3 times (CO_2 per GDP, CO_2 per PPP) higher than in Latvia and in Lithuania – close neighboring countries of Estonia (Fig. 7).

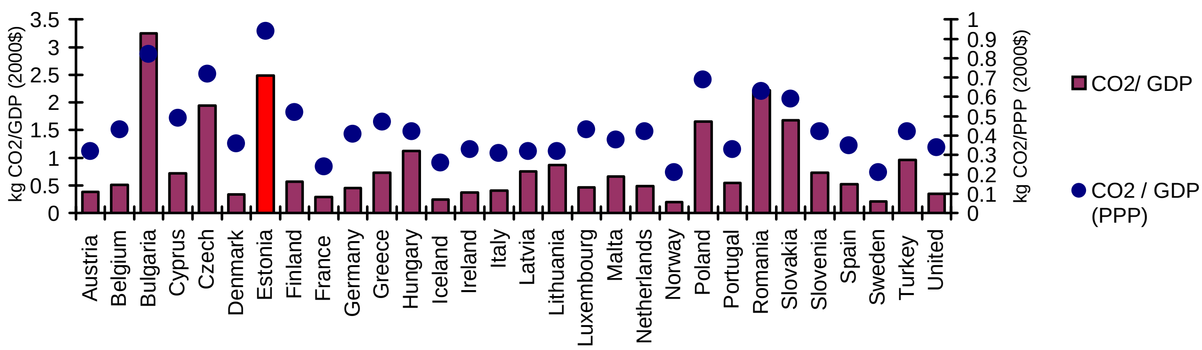


Figure 7. CO_2 emission per GDP by countries of European Union and some other countries, 2003 [Key world energy statistics 2005].

Energy intensity of an economy - how much energy is required to generate a unit of economic output - is calculated as unit of energy per unit of GDP. The Estonian energy intensity is about two times higher than the European average and 9.4 times higher than the least energy intensive country in EU, Denmark. It should be noted that Estonia's energy intensity decreased almost 1.6 times (from 1,913 kgoe/1000€ in 1993 to 1,156 kgoe/1000€ in 2003), but the comparison with most other European countries is not favourable for us.

[2]Purchasing Power Parity

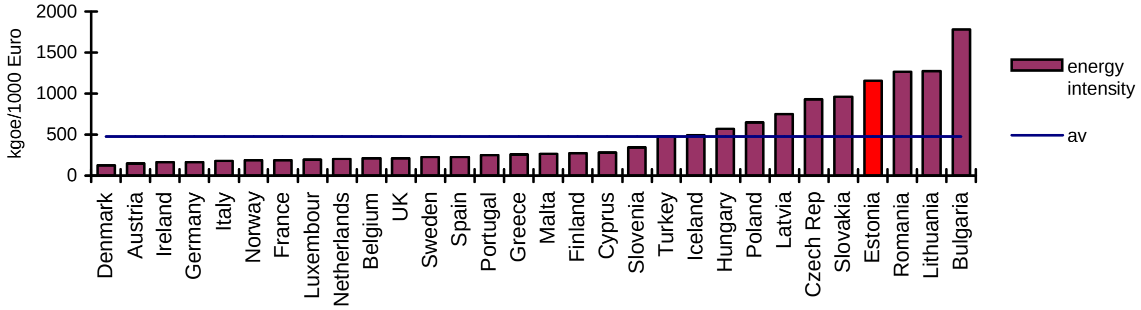


Figure 8. Energy intensity of the economy, kgoe (kilogram of oil equivalent) per 1000 Euro (at constant prices, 1995=100) [http://epp.eurostat.cec.eu.int]

1.2. Location of oil shale mining and oil shale consuming enterprises

All enterprises that operate using oil shale: oil shale mining, power plants generating energy (electricity and heat) from oil shale, chemical enterprises (shale oil production) are located in Ida-Viru county (Fig. 10, see also Fig. 1, Fig. 2 in Appendix II).

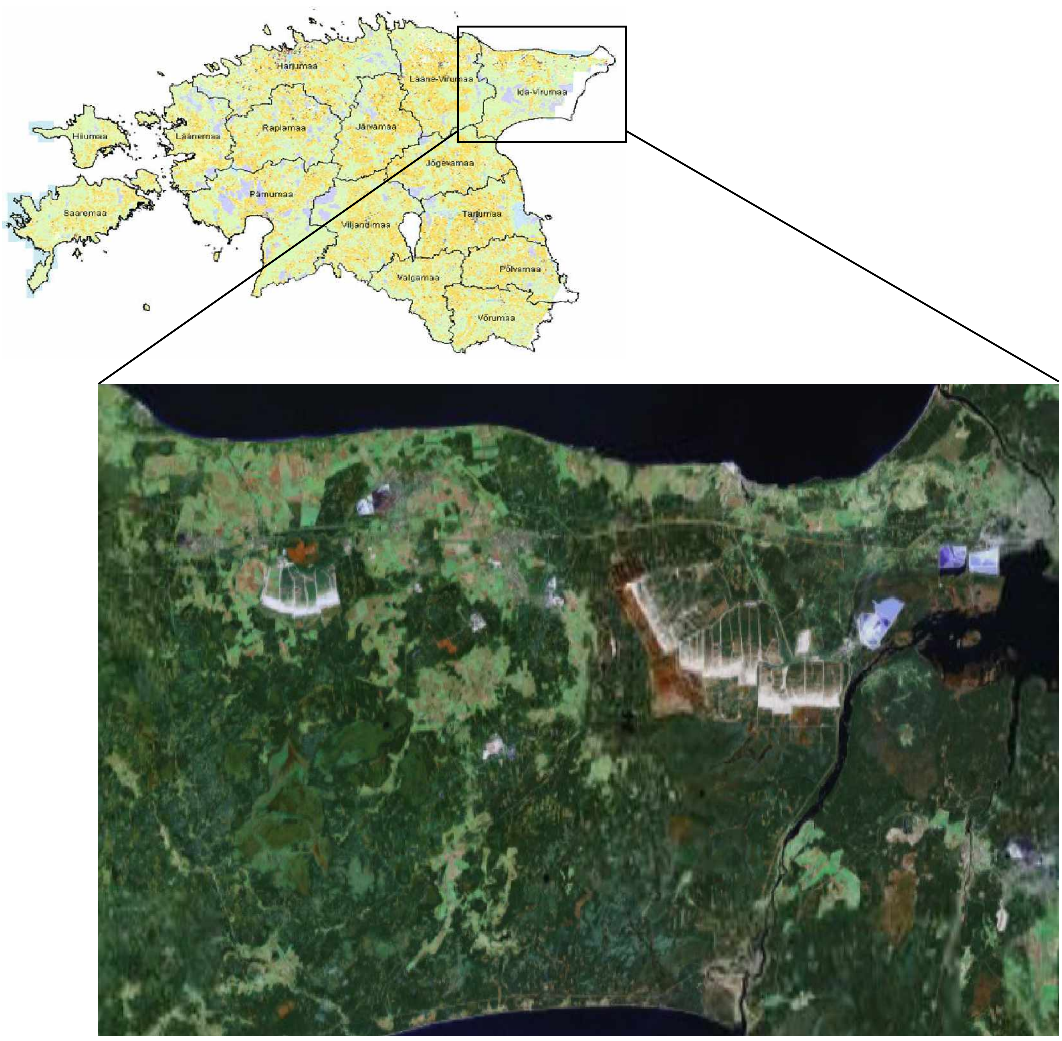


Figure 9. Northeastern Estonia, Ida-Viru county [Base map of Estonia; Google Earth $59^0$13'15.74"N, $27^0$32'20.68"E].

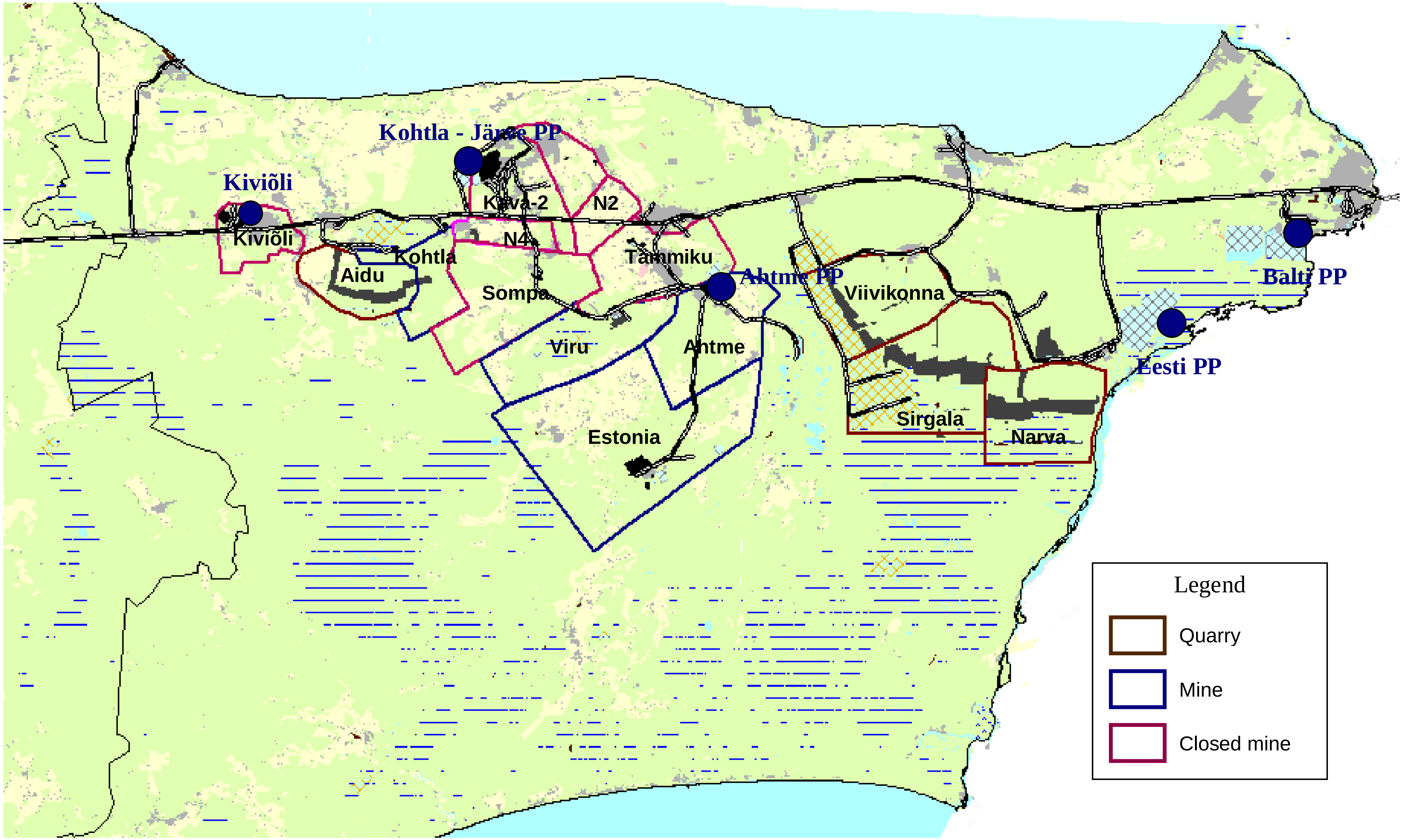


Figure 10. Map of enterprises producing and consuming oil shale [based on the Basic map of Estonia][3].

[3]Ahtme mining is closed from 2002

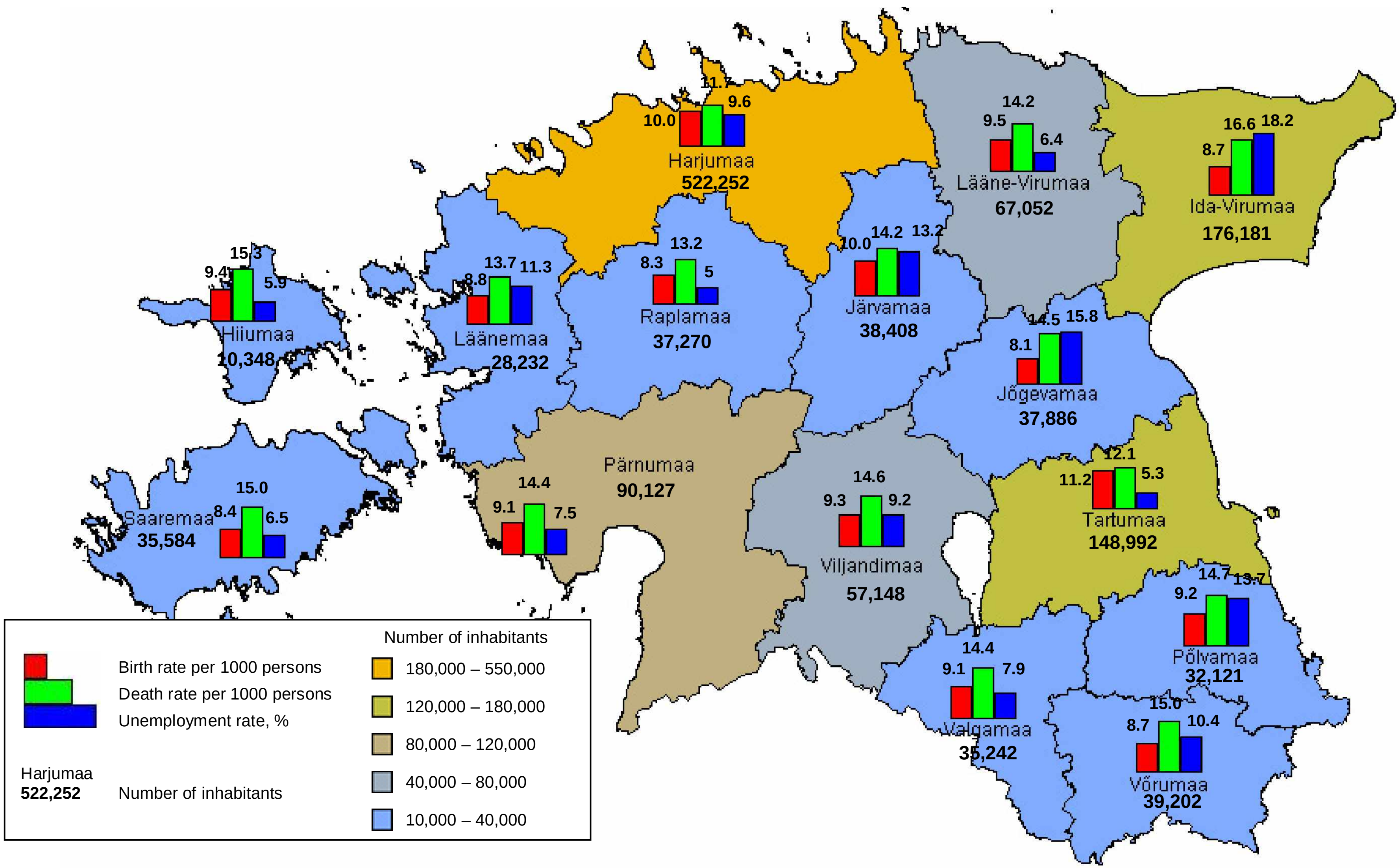


Figure 11. Social indicators of Estonia [www.stat.ee].

Opencast mines and landfills of the Narva power plants, with settling ponds, are seen well in Figure 9. The total area of mined out land is 430 km^2 – that is 12.7% of the territory of Ida-Viru county (Fig. 9, Fig. 10, Fig. 37)

1.3. Social indicators of Ida-Viru County

The territory of Ida-Viru county is about 7% of the territory of Estonia, and the population (20% Estonians, 71% Russians and 9% other nationalities) makes up about 13% of the total population of Estonia. The age structure of the population of Ida-Viru county is as follows: 0 to 19 years - 24%, 20 to 29 years – 11%, 30 to 59 years – 36%, and 60 and older – 28% of the population [www.stat.ee].

The rate of unemployment is 8.5% higher than the Estonian average and the average monthly salary is almost 2000 EEK lower (see Table 1, see also Fig. 11).

Table 1. The main indicators of Estonia and Ida-Viru county, 2004 [www.stat.ee]

Indicators	Estonian average	Ida-Viru county
Territory, km^2	45,228	3,364
Population, 01.01.2004	1,351,069	174,809
Population per 1 km^2	31.1	52
Live births per 1000 persons	9.6	8.7
Deaths per 1000 persons	13.4	16.6
Unemployment rate, %	10.3	18.9
Average monthly gross wages (salaries), EEK	6,723	4,991

1.4. Brief history of oil shale mining and consumption in Estonia

The interest in oil shale began to grow after 1910, when prices of crude oil and coal had increased on the world market. The extraction of oil shale began in Estonia in 1916 (Fig. 12), when the oil shale deposit area (57 km^2) along the railroad track between the towns of Jõhvi and Rakvere was explored. From the experimental opencast, about 22 wagons of oil shale were sent to Petrograd for testing. This exploration is considered to be the beginning of oil shale mining in Estonia.

Commercial oil shale extraction began in 1918, when about 17 thousand tonnes of oil shale was mined and the first oil shale enterprise – National Oil Shale Industry (Riiklik Põlevkivitööstus), was founded.

About 20 oil shale mining districts with a total area of 1250 km^2 had been explored by 1933. If until 1924, oil shale was used mostly as a solid fuel for the cement industry and for households, it was later also used for power generation. Oil shale extraction was interrupted by World War II, but growing demand for power by households in Leningrad and Tallinn induced a new stage of oil shale exploration after the war. 14 new oil shale fields in the central part of the Estonian deposit were explored already in 1945–1946: 60 fields in the eastern, central, and western parts of the deposit were additionally explored in 1947–1955.

The demand for oil shale grew further with the construction of two major oil shale consumers – the Balti Power Plant (1965) and the Eesti Power Plant (1973), which are still operating today.

After 1980, the demand for electricity began to decrease due to the construction of a nuclear power station in Sosnovyj Bor, and this led to a decrease in the annual oil shale output from 29.7 million tonnes in 1980 to 21.1 million tonnes in 1990 and 11.3 million tonnes in

2003 (Fig. 12). By 2003, oil shale extraction had halved compared to 1990, the base year of the Kyoto Protocol, which came into force on the 16th of February this year (see also Chapter 3.1.).

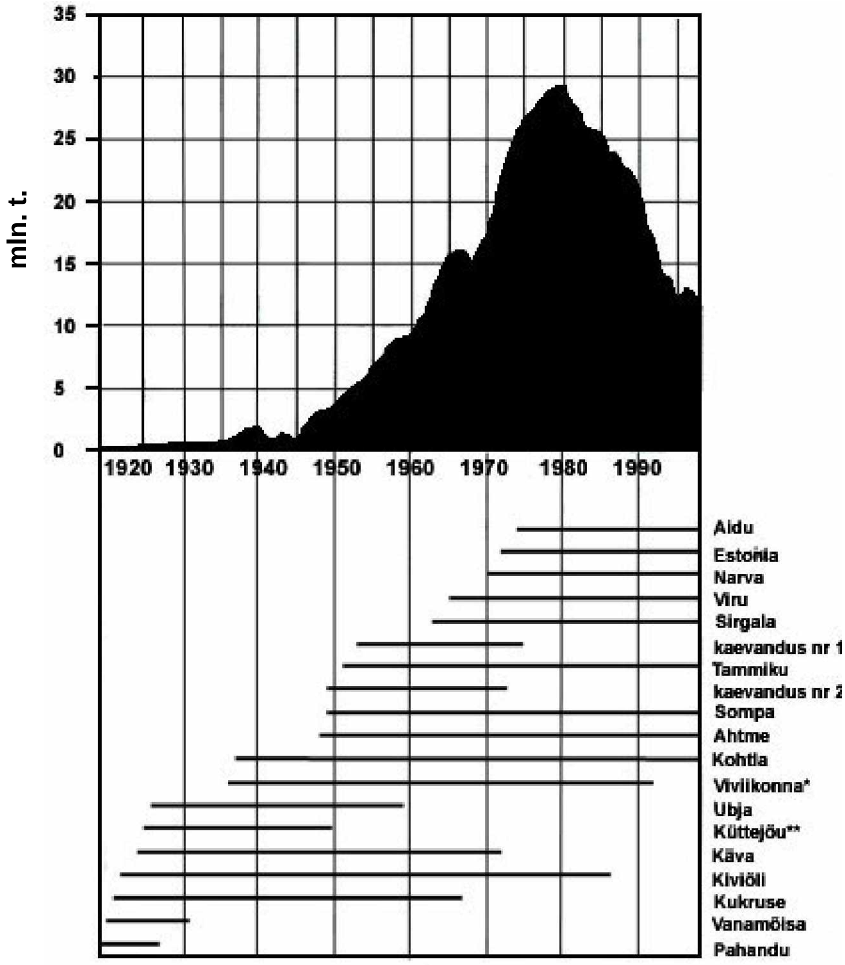


Figure 12. Oil shale production and years of operation of mines and opencasts [Kattai V., et al., 2000].

Since 1918 over 870 million tonnes of oil shale has been extracted in Estonia; that is 1.6 billion tonnes including losses and written off resources [Kattai V., et al., 2000].

2. Oil shale – a resource for energy generation

2.1. Oil shale deposits in the world

Oil shale occurs widely around the world; about 600 deposits in more than 30 countries are known [Dyni J., 2003]. Oil shale reserves are estimated at over 550 billion tonnes in oil equivalent.

Currently oil shale is extracted in Estonia, Russia, China, Brazil, Australia and Germany, but Estonia is the only state in the world where oil shale plays a central role in the economy - more than 90% of electricity is produced from oil shale (see also Fig. 4).

2.2. Chemical composition of oil shale

Kukersite (the "chemical" name of the Estonian oil shale) contains three main components: organic (kerogen), carbonaceous and terrigenous matter. The last two constitute kukersite mineral matter. The content of kerogen (organic matter of kukersite) varies from 10 to 65% [Kattai V., et al, 2000]. The content of carbon in the organic matter of kukersite is low (76.7%) and the oxygen and carbon mass ratio is 0.13. The elemental composition of kerogen and the average composition of the mineral parts are presented in Tables 2 and 3.

Estonian kukersite has a high content of hydrogen (9.7%) and a low content of nitrogen (0.3%) in the organic part. The C/H mass ratio is 8, which is close to liquid fuels. Sulphur content in the organic matter of kukersite is 1.6%. The moisture content is 9 – 12% and calorific value is 8 – 10 MJ/kg, which is lower than that for other fuels (coal – 22.5 MJ/kg, natural gas – 33.5 MJ/m^3, peat briquette – 16.5 MJ/kg).

Table 2. Composition of oil shale organic and mineral parts [Koel M., 1999]

Elemental composition of kerogen, %		Composition of mineral part, %			
		Sandy-clay part		Carbonate part	
C	76.0 – 77.5	SiO_2	59.8	CaO	48.1
H	9.4 – 9.9	CaO	0.7	MgO	6.6
S	1.2 – 2.0	Al_2O_3	16.1	FeO	0.2
N	0.2 – 0.5	Fe_2O_3	2.8	CO_2	45.1
O	9.0 – 11.0	TiO_2	0.7		
Cl	0.5 – 0.9	MgO	0.4		
H/C	1.48	Na_2O	0.8		
		K_2O	6.3		
		FeS_2	9.3		
		SO_3	0.5		
		H_2O	2.6		
	100		100		100

Table 3. The major mineral phases of kukersite [Koel M., 1999]

Calcite	$CaCO_3$	58.2 %
Dolomite	$CaMg(CO_3)_2$	12.6 %
Quartz	SiO_2	11.8 %
Pyrite	FeS_2	3.4 %
Feldspar	$K_2O{\cdot}Al_2O_3{\cdot}6SiO_2$	4.0 %
Illite	$K_2O{\cdot}3Al_2O_3{\cdot}6SiO_2{\cdot}2H_2O$	10.0 %

2.3. Oil shale deposits in Estonia

There are two principal deposits of oil shale in Estonia: Estonia and Tapa (Fig. 13). The Estonia deposit is the largest deposit within the Baltic Oil Shale Basin. The Estonia deposit is located in the north-eastern part of the country and contains oil shale of the highest quality. Further we shall consider only the Estonia deposit. The area of the Estonia deposit is about 3000 km^2, of which 1 956 km^2 is located in Ida-Viru county, 946 km^2 in Lääne-Viru County and 71 km^2 in Harju county. The deposit is divided into 5 sub-deposits (Keskosa, Idaosa, Lääneosa, Loodeosa, Lõunaosa) and 26 fields [Kattai V., et al., 2000], (see also Table 1, Table 2 in Appendix III).

Central occurrence (Keskosa) – is about 650 km^2. , Mined out areas (Pavandu, Nr 2, Nr 4, Käva-2, Kukruse) are located in the north of the occurrence; in the south of the occurrence are the Kohtla, Sompa, Tammiku, Estonia, Estonia, Viru, Ahtme, Aidu, Ojamaa and Seli fields.

Eastern occurrence (Idaosa) – is more than 530 km^2 and contains Narva, Sirgala, Viviikonna, Permisküla and Puhatu fields. The total mined out area is about 90 km^2.

Western occurrence (Lääneosa) **–** area is 630 km^2 - Kabala, Kohala, Oandu, Pada, Sonda, Uljaste, Põhja-Kiviõli and Uus- Kiviõli fields. The total mined out area is more than 30 km^2 (Ubja, Vanamõisa, Küttejõu, Kiviõli).

North-Western occurrence – (Loodeosa) – (area is 590 km^2) contains Haljala, Rakvere and Kõnnu fields.

Southern occurrence – (Lõunaosa) – (area is 570 km^2) contains Peipsi and Tudu fields.

2.4. Structure of oil shale beds

The commercial bed of oil shale in the Estonia deposit consists of seven indexed kukersite seams (A, A', B, C, D, E, F_1) and five limestone interbeds (seams) (A'/B, B/C, C/D, D/E, E/F1) (Fig. 14). The thickness of kukersite seams is different and varies between 5 and 60 cm. Most kukersite seams contain also lens-like nodules of kerogenous limestone. The thickness of limestone seams (interbeds) varies between 1 and 30 cm. The maximal thickness (2.7 - 2.9 m) of the kukersite bed occurs in central, western and northern areas of the Estonia deposit, where all working mines are located. The bed thickness diminishes to 2.1 m in the southern part of deposit and to 1.6 m in the western part. The commercial bed thickness in central and eastern parts is 2.0 - 2.2 m, 1.3 - 1.4 m in the western and southern areas of the deposit (Fig. 15, Fig. 16) [Kattai V., et al., 2000].

Three kukersite seams can be considered in a commercial bed: lower A-A’, middle – B-C and upper D-F_1 (Fig. 14). The complex is separated by interbeds A’–B, C/D [Kattai V., et al., 2000].

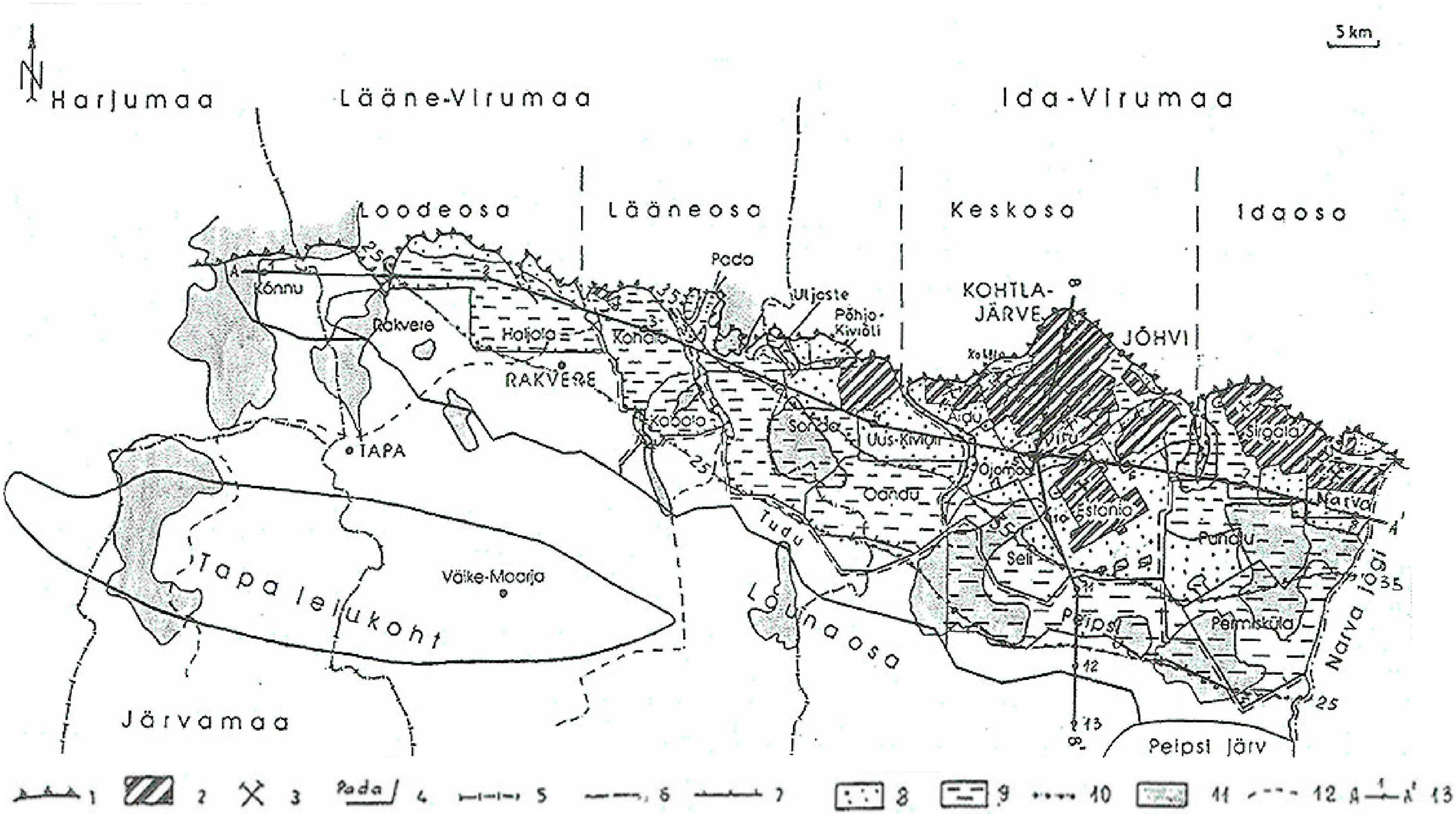


Figure 13. Distribution and development of kukersite distribution areas [Kattai V., 2003].

1 – outcrop line of oil shale bed; 2 – exhausted areas; 3 – operating mines and opencasts; 4 – boundaries of mine fields; 5 – boundaries of counties; 6 – boundaries of different parts of Estonian deposit; 7 – southern boundary of Estonian deposit; 8 – active oil shale reserve; 9 – passive oil shale reserve; 10 – isoline of energy rating (25 and 35 GJ/m^2) of the productive bed; 11 – nature conversation area; 12 – boundary of Pandivere Water Protection Area; 13 – line of cross section.

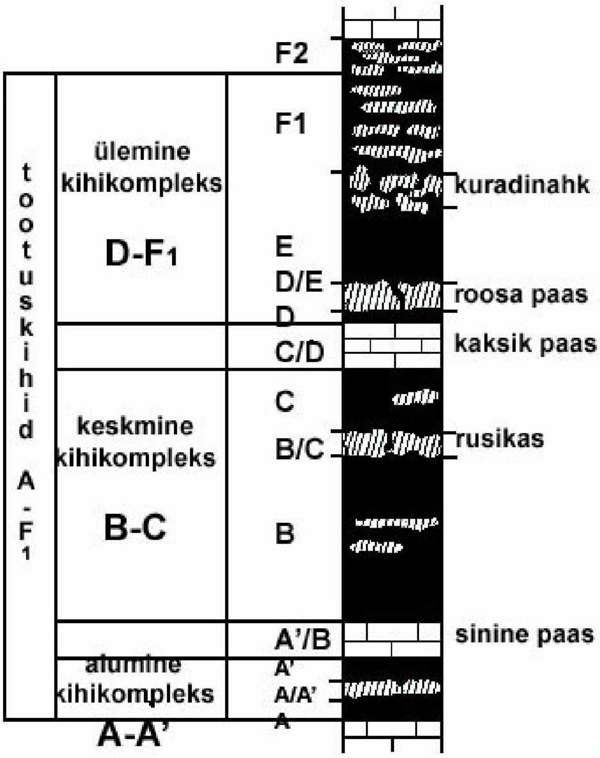


Figure 14. The commercial seams of the Estonia deposit (1 – limestone, 2 – kerogenous limestone, 3 – kukersite) [Kattai V., et al., 2000].

Oil shale seam A – is the lowest with a thickness between 0.06 and 0.17 m. The content of organic matter is 20 – 40%. The calorific value varies in the range 10 – 16 MJ/kg.

Interbed A/A' – the seam thickness doesn't exceed 0.05 m, contains limestone. The content of organic matter in the seam is 3 – 8%.

Oil shale seam A' -is with low calorific value (4 – 10 MJ/kg). The thickness of the bed is 0.04 – 0.12 m The seam includes 10-20% organic matter.

Interbed A'/B (sinine paas) – the thickness is 0.06 – 0.10 m in the north-western part; the thickness increases in a south-easterly direction to 0.20 m. The concentration of organic matter is 6 – 8% in the north-western part and 2% in the south-eastern part.

Oil shale seam B – the thickness of the seam is 0.4 – 0.6 m in the northern part, 0.10 – 0.15 in the western and southern parts. The seam contains limestone, the content of which does not exceed 15%. The concentration of organic matter is 45 – 50% in the north-eastern part and 25 – 30% in the southern part. The maximal calorific value is in eastern part more than 20 MJ/kg; the calorific value decreases to 12 MJ/kg in a western direction.

Interbed B/C – the thickness of the seam is less, 0.1 m, in western and north-western parts, and 0.15 – 0.20 m in eastern and southern parts. The concentration of organic matter in the seam is 8 – 12%. The calorific value is from 5 MJ/kg in the north-western part of the deposit to 13 MJ/kg in central and eastern parts.

Oil shale seam C – one of the most important seams. The thickness of oil shale seam C is 0.5 m in central, eastern and northern parts; the seam thins in a southerly direction to 0.25 m and in a westerly direction to 0.10 m. The seam's calorific value is high (12 – 14 MJ/kg) in central and eastern parts; the quality decreases in a southerly direction to 8 MJ/kg, and to 5 MJ/kg in a north-westerly direction. In accordance with this, the concentration of organic matter decreases from 30 – 40% to 10% respectively.

Interbed C/D (kaksikpaas) – the thickness of the seam is 0.2 – 0.3 m; the concentration of organic matter is lower than 2%.

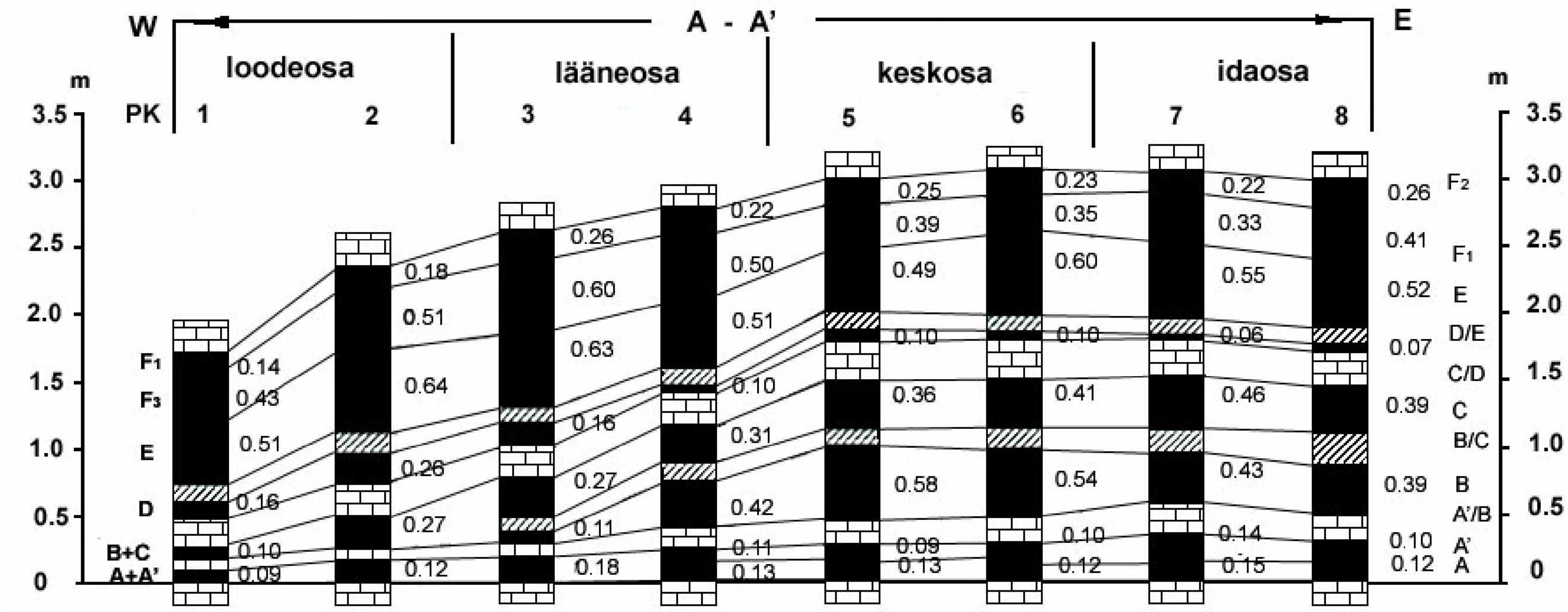
Oil shale seam D – is the thinnest seam; the thickness is 0.20 – 0.25 m in north-western part, 0.10 – 0.20 m in the western part, 0.07 – 0.12 m in central and eastern parts. The seam's calorific value is 10 – 13 MJ/kg; the concentration of organic matter changes from 35% in north-western part to 10% in eastern part.

Interbed D/C (roosa paas) – the thickness in north-western and western parts is 0.15 m; the seam gets thin in easterly and southerly directions. The concentration of organic matter is 4 – 10%.

Oil shale seam E – the thickness of the seam is 0.5 – 0.6 m in central and eastern parts, the seam thickness decreases in a southerly direction to 0.3 m. The calorific value is 14 MJ/kg in north-western part and decreases in a southerly direction.

Interbed E/F_1 (kuradinahk) – the thickness does not exceed 0.03 – 0.05 m, the concentration of organic matter is 4 – 8%.

Oil shale seam F_1 – the thickness is 0.6 m in north-western and western parts of the deposit; the thickness decreases to 0.3 – 0.4 m in central and eastern parts and to 0.2 m in the southern part. The calorific value of the seam is 10 MJ/kg in the northern part (it depends on site of dislocation), and decreases to 5.5 MJ/kg in a southerly direction.



The thickness of productive seams A-F_1, m

Thickness, total	1.61	2.23	2.41	2.60	2.73	2.79	2.82	2.69
Oil Shale seams	1.29	1.80	1.95	2.08	2.14	2.22	2.19	2.00
Limestone interbeds	0.32	0.43	0.46	0.52	0.59	0.57	0.63	0.69

The calorific value, MJ/kg (1, 2) and energy rating GJ/m^2 (3) of productive seams (A-F_1)

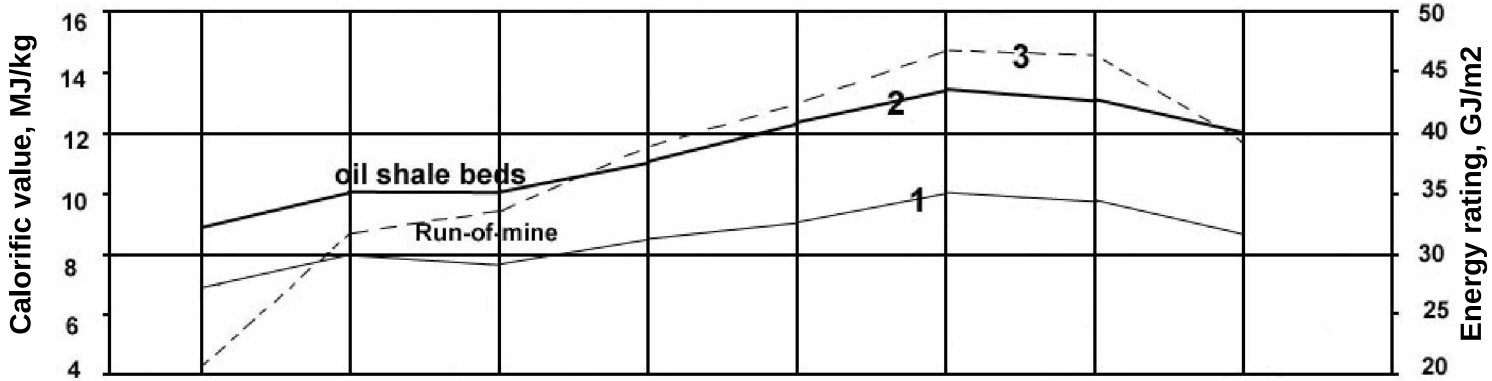
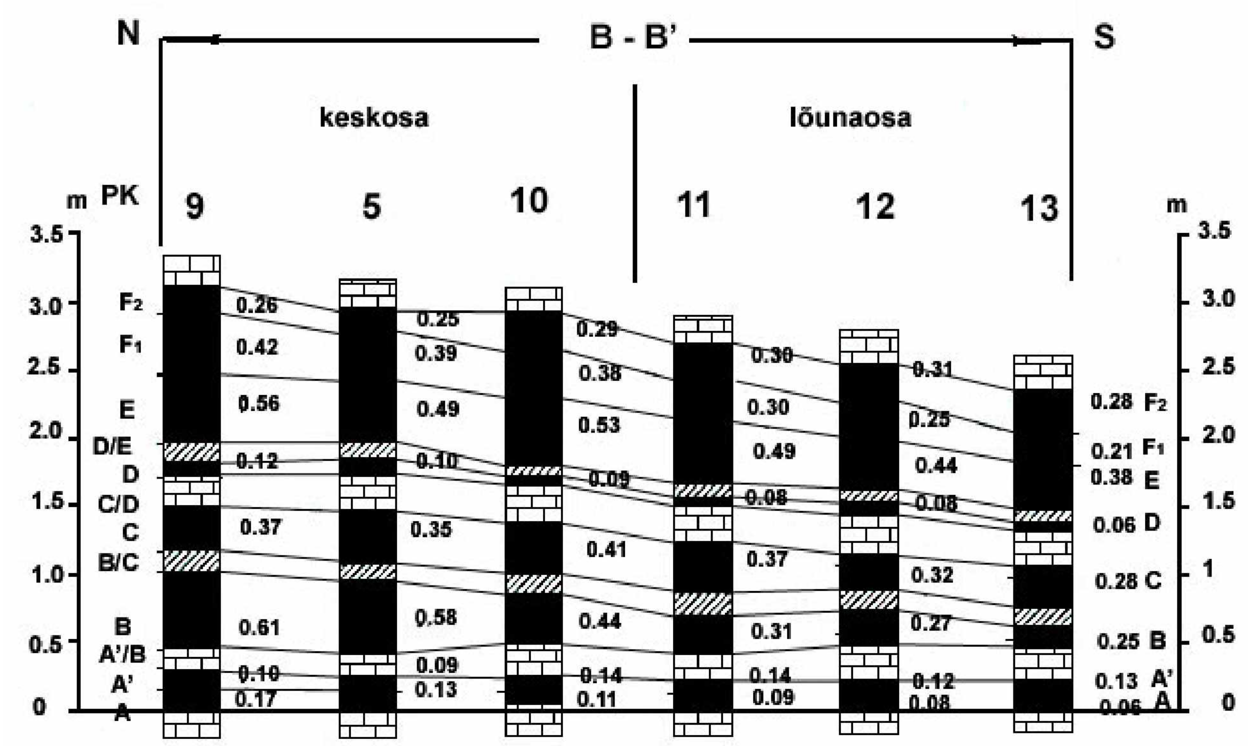


Figure 15. Estonia deposit. Changes in structure and oil shale quality on west-east profile A-A' [Kattai V., et al., 2000].



The thickness of productive seams A-F_1, m

Thickness, total	2.93	2.73	2.68	2.49	2.26	2.05
Oil Shale seams	2.35	2.14	2.10	1.78	1.56	1.37
Limestone interbeds	0.53	0.59	0.58	0.71	0.70	0.68

The calorific value (1, 2) and energy rate (3) of productive bed (A-F_1)

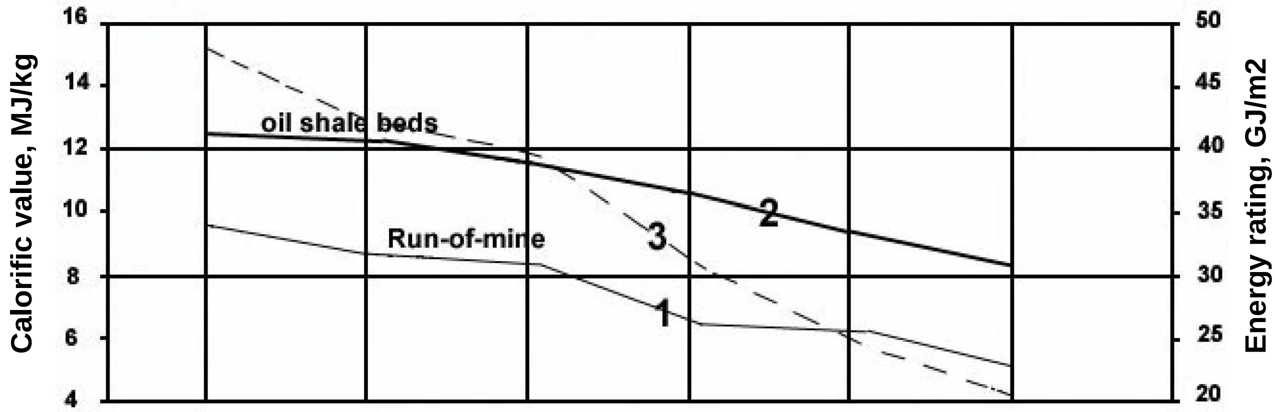


Figure 16. Estonia deposit. Changes in structure and oil shale quality on north-south profile B-B' [Kattai V., et al., 2000].

2.5. Oil shale reserves

Oil shale reserves are classified on the basis of geological and economic characteristics.

Based on geological characteristics, oil shale reserves are divided into two groups: minerable reserves, and marginally mineral reserves (Table 4). The oil shale reserves are classified taking into account bed thickness, average calorific value and depth of the mineral bed [Reinsalu E., 1998a].

Principles of economic classification of oil shale reserves were introduced by the decision of the Estonian Committee of Mineral Resources (4th December of 1997), based on the proposal made by researchers from Tallinn University of Technology [Reinsalu E., 1998a]. Oil shale reserves were classified on the basis of a profitability criterion - energy rating of economic oil shale bed must be at least 35 GJ/m^2; in the case of sub-economic beds, energy rating is in the range 25 – 35 GJ/m^2 (Fig. 17).

The limits of economically profitable and subeconomical energy ratings (35 GJ/m^2 and 25 GJ/m^2) were determined taking into account the total bed thickness (m), calorific value (kcal/kg, MJ/kg), densities (t/m^3) of all oil shale seams (A-F_1) and interbeds in all A-F seams.

Table 4. Oil Shale reserves, million tonnes, on 01.01.2002 [Reinsalu E., 2003]

	Minerable reserves		Marginally mineral reserves		Total reserves
	Measured	Inferred	Measured	Inferred	
Abandoned mining fields	**16.57**	**4.65**	**73.11**	**7.37**	**101.70**
Ahtme opencast field	0.00	0.00	27.66	3.02	30.68
Kohtla opencast field	8.76	0.38	12.85	0.65	22.64
Sompa opencast field	20.04	0	2.13	0	0
Tammiku opencast field	7.81	4.27	32.60	3.70	48.38
Operating mining fields	**512.91**	**172.43**	**150.86**	**36.25**	**872.45**
Aidu opencast field	42.82	1.96	0.89	5.33	51.00
Estonia underground field	290.41	113.38	50.71	12.60	467.10
Narva opencast field	60.76	41.14	0.00	0.00	101.90
Viru underground field	38.15	15.95	2.13	9.36	65.59
Sirgala opencast field	80.77	0.00	97.13	8.96	186.86
Total mining fields	**529.48**	**177.08**	**223.97**	**43.62**	**974.15**
In the balance of Estonian Natural resources	**1,186.04**	**301.91**	**1,759.76**	**1,750.70**	**4,998.41**

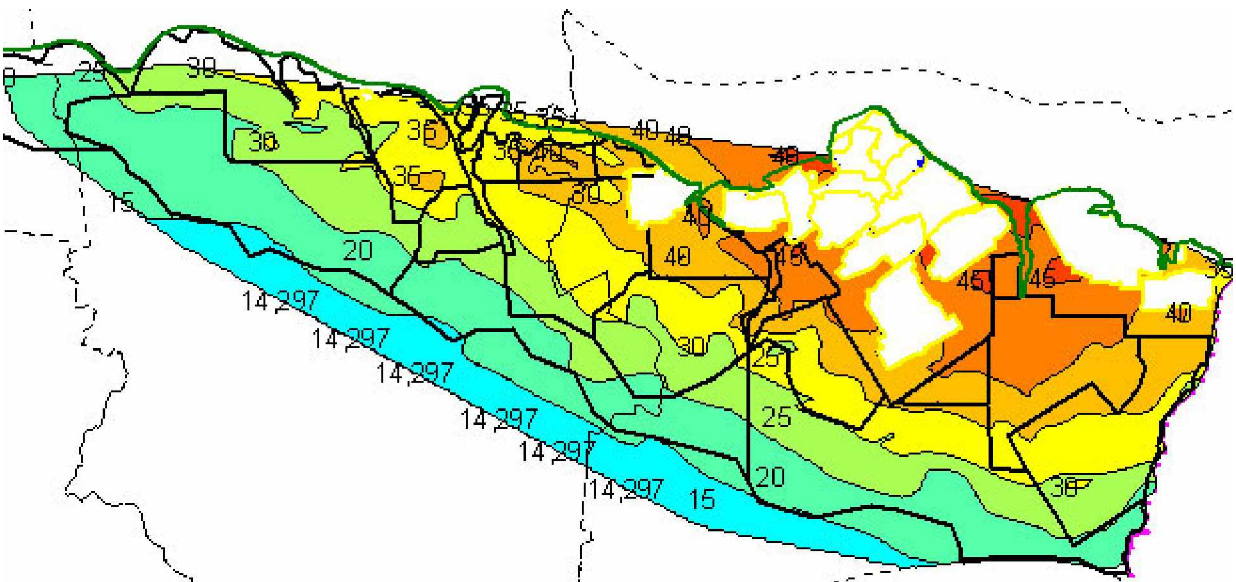
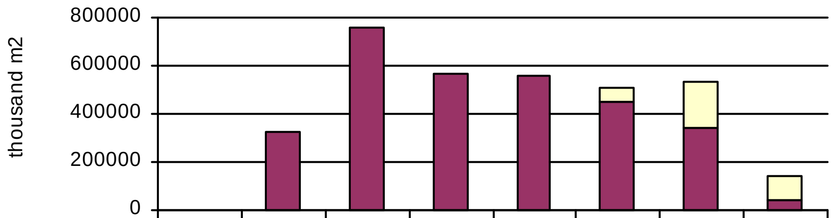


Figure 17. Location of oil shale reserves according to energy rating, GJ/m^2 [Valgma I., Estonian oil shale resources calculated…].

Based on the energy rating of oil shale bed, the oil shale economic reserves in 2002 were estimated at 1,488 million tonnes (29% of the total reserves); Estonian sub-economic reserves were calculated at 3,511 million tonnes (71% of the total) [Valgma I., 2003] (Table 2 in Appendix III).

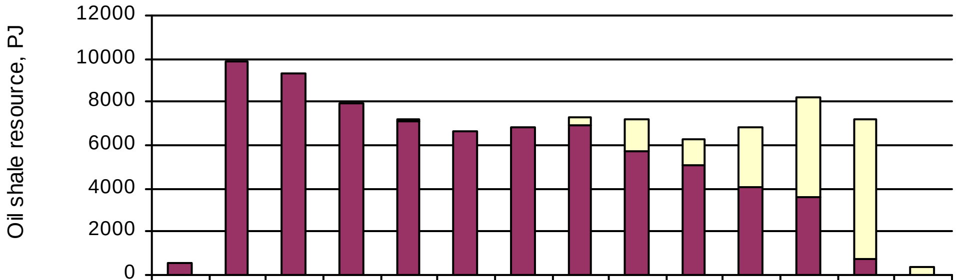
The area of the oil shale resource and the total energy value according to energy rating of oil shale is presented in Figures 18 and 19. In 2002, the total oil shale reserve was 63,265 PJ, where 44,787 PJ is deposited in oil shale beds with an energy rating 25 – 35 GJ/m^2 and 18,478 PJ in oil shale beds with an energy rating of above 35 GJ/m^2. When estimating the reserve, it was taken into account that in total 17,283 PJ of oil shale had been mined out since the commencement of commercial mining (Fig. 19). Therefore, in 2002, 18,478 PJ of economical reserves (1,488 million tonnes) were considered to be available for extraction in the future. A more detailed distribution of the oil shale reserves is presented in Figure 19.



	14-15	15-20	20-25	25-30	30-35	35-40	40-45	45-48
Mined out, 1000 m2	0	0	0	0	1875	62409	192017	104546
Unmined, 1000 m2	601	323394	760960	569117	555545	448595	337635	37999

Oil shale energy rating, GJ/m2

Figure 18. The area of oil shale resource, GJ/m^2 [Valgma I., 2003].



	21	23	25	27	29	31	33	35	37	39	41	43	45	47
Mined out, PJ	0	0	0	0	37	0	7	382	1465	1219	2790	4570	6451	362
Unmined, PJ	570	9923	9340	7939	7150	6628	6844	6886	5704	5097	4047	3630	768	0

Oil shale energy rating, GJ/m2

Figure 19. Oil shale resource, PJ [Valgma I., 2003].

The availability of oil shale resources in the future will depend on the consumption rate of oil shale (Fig. 20). The data on the period of availability of oil shale resources depending on the rate of oil shale extraction are presented in Figure 20. If the oil shale is extracted at the current rate of about 10 million tonnes per year, then the economic reserves in currently operating mines should last for 25 years. If new mines are opened, oil shale should be available for the next 40 years – during the 40 years all the economical reserves will be exhausted if the rate of extraction remains at the level of 10 million tonnes annually.

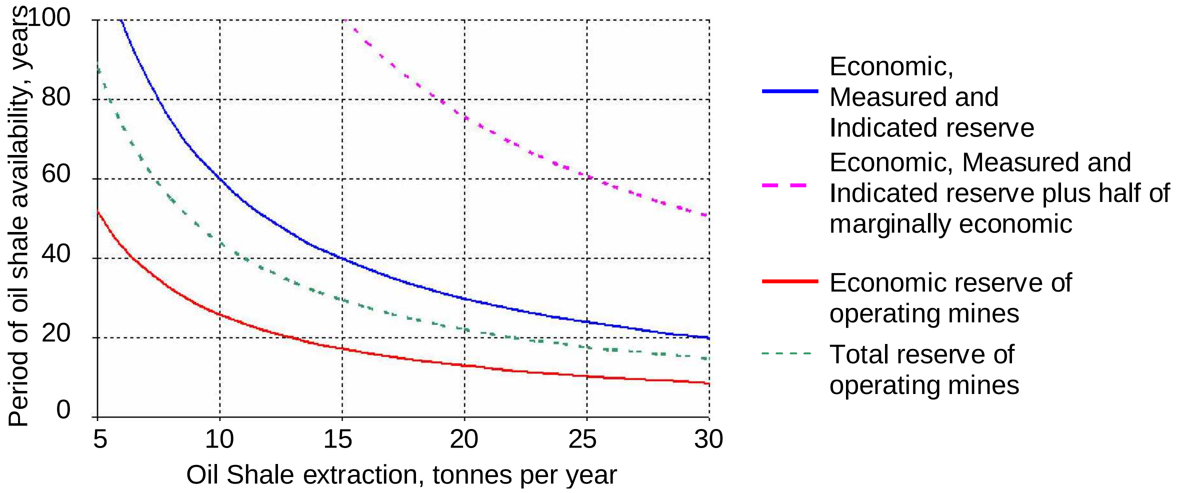


Figure 20. Period of availability of oil shale resources [Valgma I., Estonian oil shale resources calculated].

According to the calculations carried out by Reinsalu, taking into account life cycle assessment rules [Reinsalu E., 1988b], oil shale extraction from economic reserve could (should?) continue until 2020 – 2030 (Fig. 21).

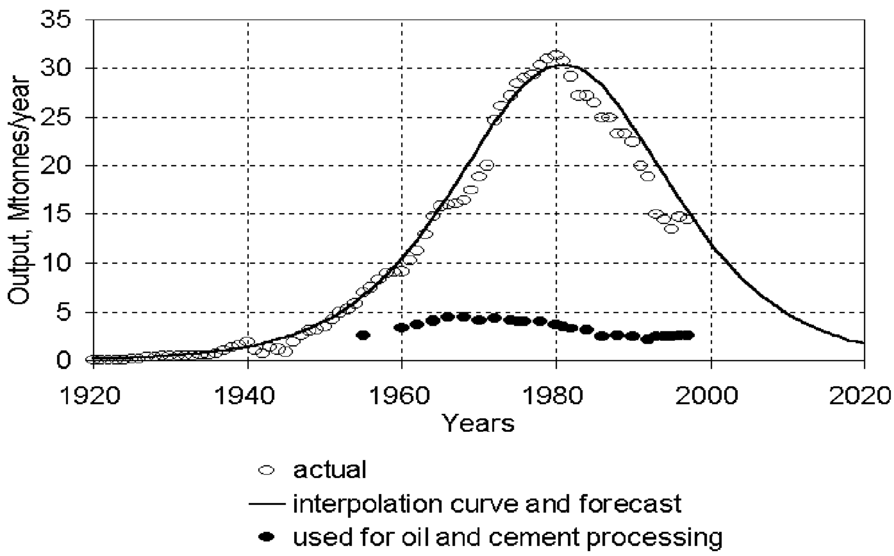
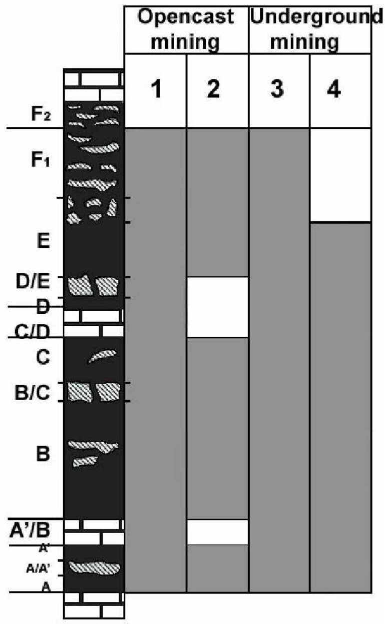


Figure 21. The prognosis of oil shale consumption, million tonnes annually [Reinsalu E., 1998b].

2.6. Technologies of oil shale mining

Oil shale is extracted by the opencast method as well as by the underground method. Currently four mines are operating: Aidu, Narva (opencast mining) and Viru, Estonia (underground mining).

Opencast mining (Fig. 9, Fig. 10, Fig. 22) is carried out at depths of 5 – 20 m; the maximal depth for opencast operation is 25 – 27 m. The oil shale extraction in opencast mines is carried out by two types of operations: full-face mining and partly selective mining [Kattai V., et al., 2000].



1 – Full-face mining;
2 – Partly selective mining;
3 – Room and pillar mining;
4 – Longwall face mining;

Figure 22. Schemes of oil shale mining [Ots A., 2004]. The layers not coloured are not extracted.

The excavation of oil shale by the method of **partly selective mining** is used in Narva mine (Fig. 22, column 2). The extraction is carried out on three terraces: upper (kukersite seams F_1 and E), lower (oil shale seams C and B and limestone interbed B/C), and middle (limestone interbeds D/E, C/D and oil shale seam D), which is stored directly onto spoil heaps. This method of extraction does not require oil shale enrichment after mining. Oil shale losses in the process using this method are more than 10% [Kattai V., et al., 2000].

Full-face method of mining (Fig. 22, column 1) is used in Aidu opencast. In Aidu, oil shale extracted is enriched in the enrichment plant. Oil shale losses in the case of using this method of extraction are about 5% of the resource. In Aidu, oil shale seams (A-F_1 seams) are excavated obliquely from north to south. Thus the face is the lowest place of the opencast, and all the mining water is flowing towards this lowest location [Kattai V., et al., 2000].

Underground mining (Fig. 10, Fig. 22 columns 3, 4) is carried out at depths of 10 – 65 m. One of the methods that is used in the process of underground mining is the **room-and-pillar method** (the most exploited method). This technology is currently used in the Estonia and Viru mines. The same technology was used in the now abandoned Ahtme and Tammiku mines.

All kukersite seams (A-F_1) are extracted. Oil shale enrichment plants are used in Estonia and Viru mines.

The hard roof of extracted areas is held up by protective pillars – by columns of unextracted oil shale. Oil shale losses with this technology exceed 25-30% in the whole extracted area [Kattai V., et al., 2000]. All the areas mined using room-and-pillar method are considered unstable and/or quasistable – Table 5 (see also Table 2, Appendix VI).

Other (less used) methods of underground extraction of oil shale are **longwall face technology** (Fig. 22, column 4) and **longwall manual technology** of mining.

Oil shale extraction by longwall face technology is used in areas of oil shale deposit with anomalous structure of oil shale seams. Only A, A', B, C kukersite seams and partly D with limestone are extracted by this technology of mining. Oil shale losses using longwall technology are 26 – 30% [Kattai V., et al., 2000].

Table 5. Estimated areas of mined out land in rural municipalities [Ida-Viru maavalitsus..., 2001]

	Mäetaguse	Illuka	Maidla	Sonda	Kohtla	Vaivara	Toila	Jõhvi	Jõhvi town	Kohtla-Järve town
The area of rural municipality, km^2	285.043	543.815	332.299	148.083	101.556	397.966	169.661	116.447	7.615	47.765
Mined out area, %	**> 23%**	**> 3%**	**> 10%**	**> 4%**	**> 18%**	**> 18.5 %**	**16 %**	**> 70 %**	**> 11.5 %**	**> 2 %**
…by underground method	> 23%	> 2.8%	>4%	> 4%	>18%			> 70 %	> 11.5 %	> 2 %
room-and-pillar mining	19%	2%	0.5%		> 1%			58%	> 4 %	0.5 %
longwall manual mining	2%	0.8%	> 3%	> 4%	14 %				> 7 %	≈ 2 %
longwall face mining	> 2%		> 0.5%		> 3%				0.5 %	
…by opencast method		> 0.2%	6%			> 18.5 %	16 %			
Mines	Estonia, Viru, Sompa	Estonia, Ahtme, Sirgala	Aidu, Kohtla, Kiviõli	Kiviõli	Kohtla	Sirgala, Viviikonna	Sirgala	Ahtme	Kaevandus nr2 Tammiku	Pavandu
Classification of mined area	quasistable	quasistable			Subsided, steady / quasistable			quasistable	Kaevandus nr2 - quasistable	quasistable

See also: Appendix II. Figure 1. The map of Estonian counties; Figure 2. The map of rural municipalities of Ida-Viru county.
Appendix IV. Figure 1. Mined out land by rural municipalities.
Appendix VI. Table 6. Allotment of areas, influenced by underground mining of oil shale.

2.7. Oil shale enrichment

The next stage in the industrial chain, after oil shale extraction, is enrichment. Oil shale enrichment is a process of separating big particles of limestone from oil shale. The enrichment increases the calorific value of extracted oil shale.

Oil shale enrichment was used in underground mines (Viru, Estonia) and Aidu opencast in 2002.

Oil shale losses in the enrichment process were estimated by Kattai [Kattai V., at al., 1971] and Reinsalu [Reinsalu E., 1988a] at 0.1 – 5% of the total mass of extracted oil shale.

2.8. Oil shale consumption (uses of oil shale)

As said, the main industrial activities where the oil shale resource is used are electricity and heat generation and conversion to other forms of fuels (shale oil, shale oil gas) (Fig. 23).

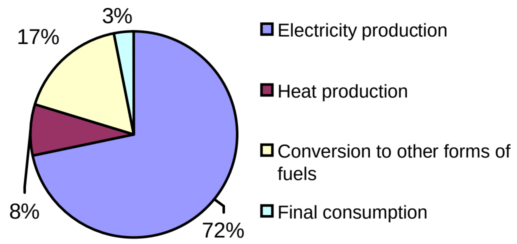


Figure 23. Oil shale consumption by activities, 2002 [Energy balance 2002]

Narva Power Plants (PPs) and Kohtla-Järve Combined Heat and Power Plants (CHPs) used about 86% of the total oil shale extracted in 2002 (Fig. 24). 12% of the total was sold to the chemical industry for production of shale oil; 1% was used for the production of cement.

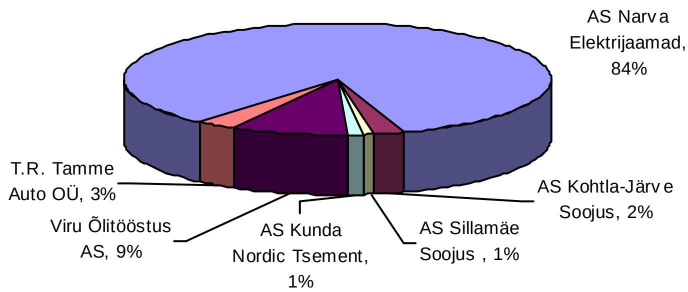


Figure 24. Oil shale consumption by consumers, 2002 [www.ep.ee/?id=1599]

2.8.1. Oil shale consumption for electricity and heat generation

As mentioned, about 95% of generated electricity in Estonia was produced from oil shale in 2002 (Fig. 4); the share of heat generation from oil shale was 8% of the total heat generation in Estonia in 2002. The structure and the total energy output of power plants are presented in Figure 25. The structure of oil shale consumption has remained practically the same until now.

The total output of energy (electricity + heat) was 7,799 GWh by Narva PPs (Balti PP (CHP)+Eesti PP) and 606.3 GWh by Kohtla-Järve CHPs (Kohtla-Järve CHP+Ahtme CHP) in 2002. Heat emission into the environment (mainly water of Narva River) from Narva PPs was 12,150 GWh (3,508 GWh from Eesti PP and 8,642 GWh from Balti PP), that is 156% of the

„useful” energy output from Narva PPs. There was no heat emission into the environment from Kohtla-Järve CHPs [Eesti Energia Environmental…, 2002].

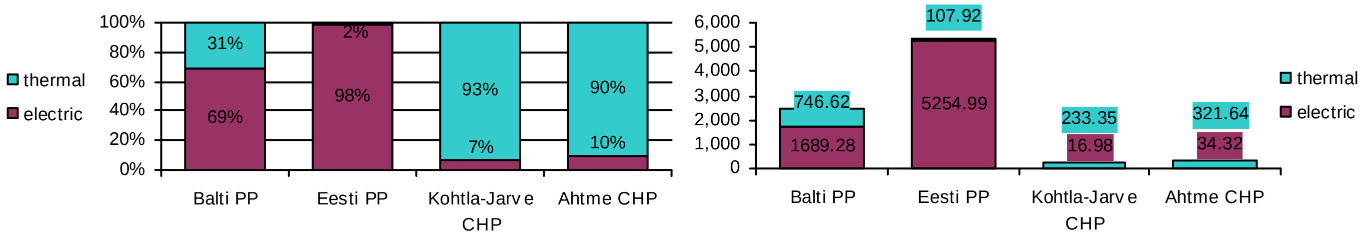


Figure 25. The structure and output of electricity and heat by power plants in 2002, % and GWh [Eesti Energia Environmental…, 2002]

2.8.1.1. Oil shale combustion technology

Pulverized Firing Technology (PFT) and Circulating Fluidised Bed Technology (CFBT) are used in oil shale combusting power plants currently. The installation of boilers with Circulating Fluidised Bed Technology was carried out in 2004-2005. Power Unit No. 8 (Eesti PP) and Power Unit No. 11 (Balti PP) were replaced on May 30th 2005 by CFB boilers with maximum power of 215 MW_{el}. The main reason for the installation of the new boilers was the reduction of the negative impact to the environment and the achievement of the environmental requirements of the European Union in decreasing emissions of SO_2, NO_X, and particulates into air (analyzed in more detail in Chapter 3.1. Emission into air).

The burning of oil shale using PFT takes place at a temperature of 1,400^{0}C – 1,500^{0}C [Ots A., 2004]. The main problem of using this technology is the high concentration of SO_2 (~ 700 mg/MJ) and particles (~ 550 mg/MJ) in flue gases [Arro H., et al., poster].

The burning of oil shale using CFBT takes place at a temperature of 850^{0}C. This temperature is considered to be the most suitable for the binding of SO_2 by CaO [Arro H., et al., 1997], leading to a 100–130 fold decrease in SO_2 emission [Liblik V., et al., 2002].

2.8.1.2. The Balti Power Plant

The Balti power plant was built in 1959-1966 (Fig. 26). Balti PP is located 5 km south-west of the town of Narva (see Fig. 28). The installed capacity of Balti PP was initially 1624 MW of electricity and 505 MW of heat [Ots A., 2004]. The old part of the plant, initially installed, had eighteen TP-17 boilers and eight 100 MW_{el} turbines. Fourteen of the TP-17 boilers and six turbines installed in the old part of the plant were closed before 2005. The newer part of the plant (power units 9, 10, 11 and 12) had eight TP-67 boilers and four 200 MW_{el} turbines. In 2004-2005, one CFB boiler with maximum capacity of 215 MW was built. Currently eight TP-67 boilers with a total capacity 720 MW in addition to the CFB boiler (215 MW) are operational together with two 100 MW_{el}, four 200 MW_{el}, and two 12 MW_{el} turbines.

Two boilers TP-67 are equipped with new efficient electrostatic precipitation units (EPS) for the collection of the flying ash, while the other blocks have old, less efficient ESPs. Ash from oil shale burning was (is) disposed to an ash-mound next to the power plant (Fig. 28) according to a disposal permit, using a water ash handling system.

Balti PP is using oil shale from AS Viru Kaevandus (Viru mining) and AS Eesti Kaevandus (Estonia mining) for electricity and thermal energy generation (for location of the underground mines see Fig. 10).

Balti PP is connected with power lines of 110KV, 220KV and 330KV (Fig. 29).

Balti PP produced 1,690 GWh of electricity and 747 GWh of thermal energy (in total 2,437 GWh) in 2002 [Eesti Energia Environmental…, 2002].

Figure 26. The Balti Power Plant [www.galerii.ee/panoraam/eesti/e_sisu.html?id=126]

The data on the efficiency of electricity and heat generation before completion of the renovation of power units are presented in Table 6 [www.energia.ee/OSELCA]. The efficiency of electricity generation had been estimated at about 27% in 1990ies [Possible energy…, 1999. p.–134].

Table 6. Net efficiency of the Balti Power Plant [Talve S., et al., 2005; Veiderma M., 2003]

	till renovation		after renovation	
	Electricity	Heat	Electricity	Heat
Net efficiency, %	28.2%	68%	max 32 – 34%	

2.8.1.3. The Eesti Power Plant

The Eesti power plant was built in 1969 - 1973 (Fig. 27). The power plant is located 25 km south-west of the town of Narva (see Fig. 10 and Fig. 28). The Eesti PP is the biggest power plant using oil shale for electricity production in the world. The available capacity is 1,610 MW of electricity and 84 MW of heat [www.powerplant.ee]. Eesti PP initially had sixteen TP-101 boilers, seven 200 MW_e steam turbines and one 210 MW_e steam turbine. Fourteen boilers and seven turbines were in service in 2002. Two boilers TP-101 of the 8th power unit were replaced by one new circulating fluidised bed (CFB) boiler with maximum power output of 215 MW.

The new efficient electrostatic precipitation units for flying ash collection (EPS) have been installed onto ten boilers (5 power units). Bottom ash from the boilers and dry ash are deposited next to the power plant.

Cooling water to Eesti PP is supplied from the Narva River and Mustjõgi River via a 7 km long open channel.

Eesti PP produced 5,255 GWh of electricity and 108 GWh of thermal energy (in total 5,363 GWh) in 2002 [Eesti Energia Environmental…, 2002].

Figure 27. The Eesti Power Plant [www.powerplant.ee/eej_3.php]

The data on the efficiency of electricity generation before and after the last renovation of the power units is presented in Table 7 [Possible energy…, 1999. p.–134], and are unofficial. It is important to underline that the maximal efficiency of electricity generation from oil shale using PFT is 30%.

Table 7. Net efficiency of the Eesti Power Plant [Possible energy…, 1999; Veiderma M., 2003]

	till renovation		after renovation	
	Electricity	Heat	Electricity	Heat
Net efficiency, %	29%		max 32 – 34%	

Figure 28. Location of Balti PP and Eesti PP with ash disposal areas and settling ponds [Google Earth - $59^0$19'12.67"N, $27^0$52'31.04"E].

2.8.1.4. The Kohtla-Järve Combined Heat and Power Plant (CHP)

The Kohtla-Järve CHP was built in 1954-1958. The CHP is located in Järve town district of Kohtla-Järve (Fig. 10). The available capacity is 39 MW_e of electricity and 534 MW_h of heat. BKZ-75-39F boilers are installed in Kohtla-Järve CHP [www.powerplant.ee]. The first priority for building Kohtla-Järve CHP was to provide electricity and heat to shale oil producing chemical plant.

Kohtla-Järve CHP produced 17 GWh of electricity and 233 GWh of thermal energy in 2002 [Eesti Energia Environmental…, 2002].

The data on the efficiency of electricity and heat generation presented in Table 8 [Possible energy…, 1999. p.–134] are unofficial.

Table 8. Net efficiency of the Kohtla-Järve Plant [Possible energy…, 1999].

	Electricity	Heat
Net efficiency, %	11%	44%

2.8.1.5. The Ahtme Combined Heat and Power Plant (CHP)

The Ahtme CHP was built in 1953-1956. The CHP is located in the Ahtme district of Kohtla-Järve town. The available capacity is 30 MW_e of electricity and 370 MW_h of heat. Middle-pressure boilers – BKZ-75-39F – are installed in the power plant.

The first priority of the Ahtme Plant was provision of electricity and heat to new mines in the region, but later the heat transmission lines of the Plant were joined to the regional heat transmission lines and Ahtme Plant began to provide heat to Ahtme town [www.powerplant.ee].

Water needed for cooling (cooling water) is taken from Konsu Lake, which is a nature reserve area.

Ahtme CHP produced 34 GWh of electricity and 322 GWh of thermal energy in 2002 [Eesti Energia Environmental…, 2002].

The data on the efficiency of electricity and heat generation presented in Table 9 [Possible energy…, 1999. p.–134] are unofficial.

Table 9. Net efficiency of the Ahtme Plant [Possible energy…, 1999]

	Electricity	Heat
Net efficiency, %	8%	56%

2.8.1.6. The Power Network

Currently The National Grid (AS Põhivõrk) is a daughter company (independent subsidiary) of AS Eesti Energia. The main function of The National Grid is to transmit electric power from producers to major consumers and the distribution network.

The transmission network is seen on Figure 29. Electricity is carried by 330 KV, 220 KV and 110 KV high voltage lines.

The transmission network consists of 5,193 km of high-voltage power lines (3,395 km of 110 KV lines (66%), 439 km of 220 KV lines (9%) and 1,297 km of 330 KV lines (25%)) and operates 142 substations. The power losses in transmission lines were 3.7% in 2002 [www.energia.ee].

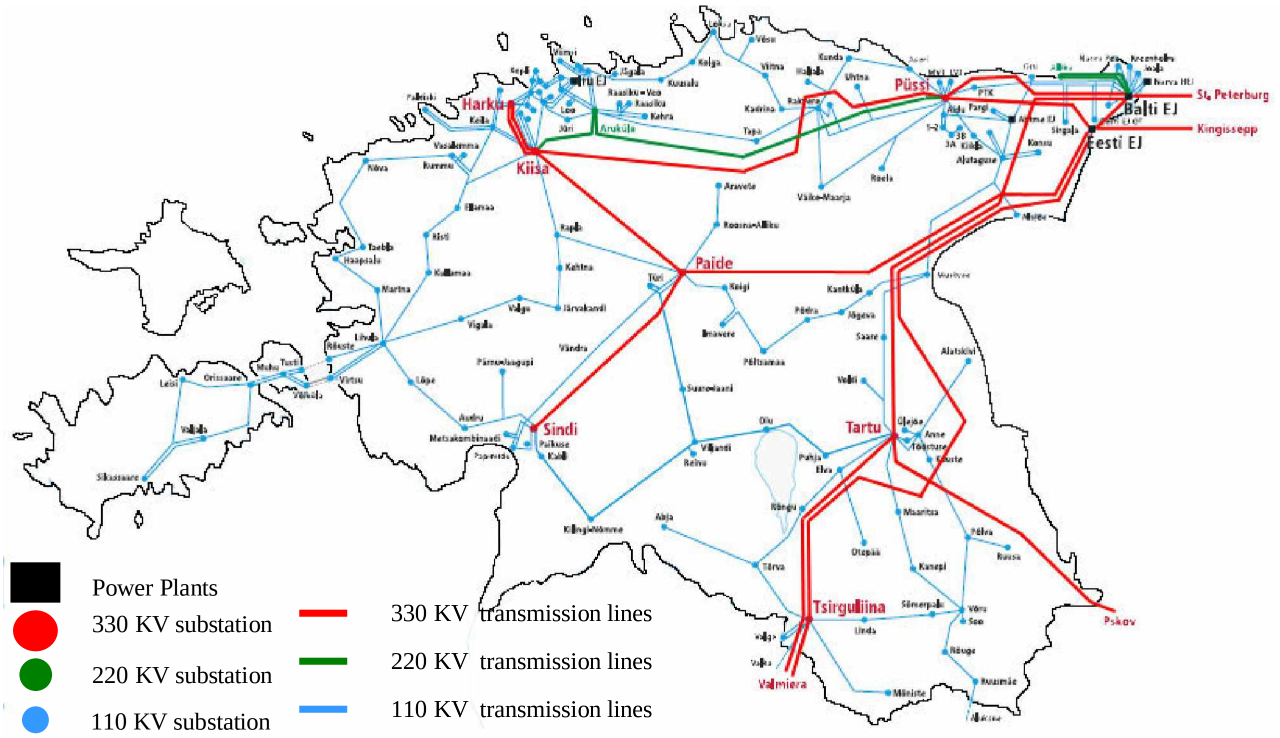


Figure 29. Map of the power system – transmission network and the major power stations [The map of Estonian…].

The main aim of the Distribution Network (Jaotusvõrk) is to deliver electricity to final consumers via low- and medium-voltage networks (6, 10, 15, 20 and 35 KV). The company operates over 18,000 substations and more then 60,000 km of power lines. The electricity losses in the distribution network were 11.9%.

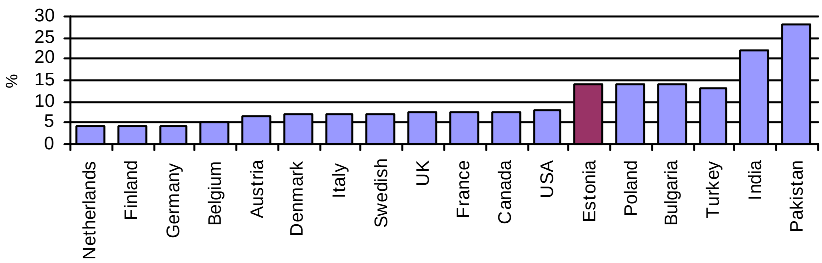


Figure 30. Electricity losses in transmission and distribution network by countries, 1996 - 1998 [Tammoja H., 2004a].

As seen from Figure 30, Estonian electricity losses are high in comparison with other countries in the European Union.

Another important peculiarity is the tree-like structure of 220 KV and 330 KV high voltage-lines – they all start from Narva city area. The structure of the National Grid is designed to serve the centralized power generation system.

2.8.2. Shale–to–oil processing – oil shale chemical industry

Currently shale oil is produced by AS Viru Keemia Grupp (Kohtla-Järve), OÜ Kiviõli Keemiatööstus (Kiviõli) and AS Narva EJ Õlitehas (Eesti PP, Narva).

The capacity of generators for producing shale oil is as follows [Kattai V., 2003]:
AS Viru Õlitööstus – different, 40-1,000 tonnes of shale oil per day;
OÜ Kiviõli Keemiatööstus – 100 tonnes of shale oil per day;
AS Narva EJ Õlitehas – 3,000 tonnes of shale oil per day.

AS Viru Keemia Grupp (AS Viru Õlitööstus) operates generators using the "**Kiviter**" process (vertical retorts) (see [Koel M., 1999]).

Oil yield is 17 – 17.5% of the oil shale used; production of gas is 380 – 430 m^3 per tonne of oil shale; the chemical efficiency of the process is 72 – 75% [Soone J., et al., 2003].

AS Narva EJ Õlitehas is operating plant UTT-3000, which was built in 1980 at Narva PP. The plant operates according to the "**Galoter**" process (with solid heat carrier) [Golubev N., 2003].

Oil yield is 13.6% of the oil shale used; production of gas is 40 m^3 per tonne of oil shale; the chemical efficiency of the process is 80 – 85% [Koel M., 1999].

2.9. Efficiency of oil shale industry

Figure 31 illustrates the flows of oil shale from extraction to final products to consumers, in other words - the efficiency of the oil shale industry. Data from 2002 were used in calculations. This year was a quite representative one, since the most inefficient mines were already closed by this time (Sompa in 1999, Kohtla in 2000 and Ahtme in 2002).

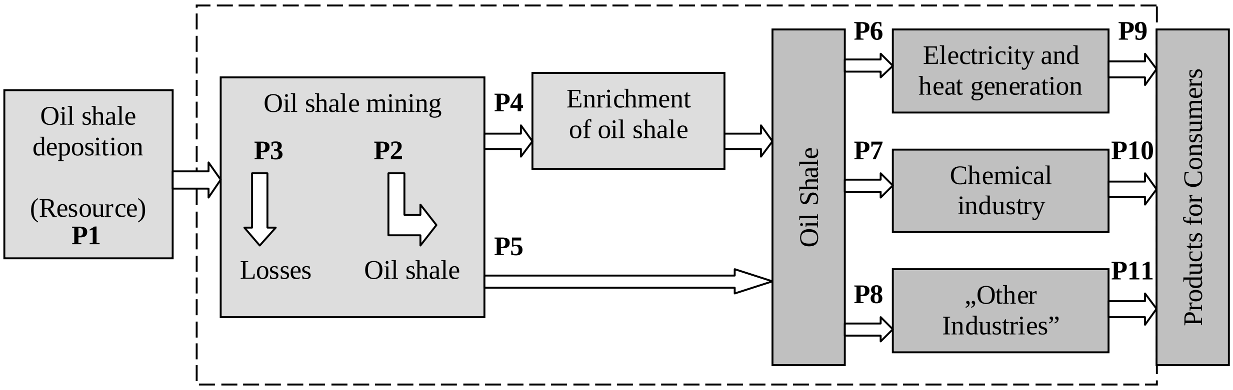


Figure 31. A scheme of material flows and efficiency of the Estonian oil shale industry

The flows on the Figure 31 are defined as follows:

P1	Oil shale reserves, minerable reserves and marginally economic reserves
P2	Oil shale extraction
P3	Oil shale losses in mining
P4	Oil Shale to enrichment
P5	Oil Shale to consumers without enrichment
P6	Oil Shale for electricity and heat generation
P7	Oil Shale for chemical industry (for shale oil production)
P8	Oil Shale for "Other Industries" (cement)
P9	Heat and electricity consumption by consumers (end-users other than "AS Eesti Põlevkivi")
P10	Products of chemical industry – shale oil etc. to the end-users (data not considered)
P11	Products of "Other Industries" (cement) to the end-users (data not considered)

2.9.1. Efficiency of oil shale extraction

Currently oil shale is extracted in four mines (Table 10, Fig. 10). The total amount of oil shale extracted was 10,513 thousand tonnes in 2002, with 47% extracted by opencast methods and 53% by underground methods.

Table 10. Oil shale extraction and losses in 2002, 1000 tonnes, official data [the data of "AS Eesti Põlevkivi"]

	Mine	Oil shale extraction, 1000 tonnes	Oil shale losses, 1000 tonnes	% from oil shale extraction
Underground mines	Viru	1,630	568	25.8%
	Estonia	3,985	1,665	29.5%
Open-cast mines	Narva	3,363	393	10.5%
	Aidu	1,535	63	3.9%

According to the official data, the losses in underground mining were about 28% (caused by un-mined supporting pillars) and less than 10% by opencast mining. Thus, according to the official data (Table 10), the mining efficiency in 2002 was about 79.6%.

However, these data do not give a full picture about of oil shale losses, because another type of oil shale loss also exists – written off oil shale reserves. The reasons for writing off oil shale reserves may be different: difficult geological-hydrological conditions, preventative and protected cranches, oil shale cranches under objects that are not connected with the extraction of oil shale reserves, liquidation of mines, transferral of mine able oil shale reserves into marginally economic reserves due to technical-economic reasons.

"The Balance of Estonian Natural Resource" report, which "AS Eesti Põlevkivi" completes and presents annually to the Statistical office of Estonia, contains a column – "Exploring, overestimation and change of borders", where written off oil shale reserves are described (Table 11).

Table 11. Written off and added oil shale reserves, 1000 tonnes [The balance of oil shale..., 1997-2003]

Mine	1996	1997	1998	1999	2000	2001	2002
Sompa	-8	1	-1				
Viru		-10	-9	1047		-4002	-702
Tammiku			2888			-2	-2206
Ahtme	-15	-96	-57	-43	-831	-22297	
Kohtla	-2	-15	1074	4243	-502	-15	
Estonia	-87	-74	-50	-44	-85	20299	-256
Underground total	-112	-194	3845	5203	-1418	-6017	-3164
Viivikonna			857		6585		
Sirgala				-8103	2640		
Narva	-18	-13	-32	-28			
Aidu	41	-86	-60	-44	-26	-22	-25
Kohtla					28	39	441
Opencast total	23	-99	765	-8175	9227	17	416
AS Eesti Põlevkivi	-89	-293	4610	-2972	7809	-6000	-2748

The amount of overestimated oil shale reserves has changed significantly from one year to another during the last seven years. When oil shale resources are added into mine able reserves, it gives additional profit for the extraction of oil shale, but if oil shale resource is written off, this does not affect the efficiency of oil shale mining and is not considered as an oil shale loss. Therefore the company is interested in writing off as much of the resource as possible.

Kattai [Kattai V., et al., 1971] stated in the report “Analysis of the efficiency of extraction and usage of commercial beds of Estonia oil shale deposit” that “Oil shale mining enterprises had systematically written off oil shale reserves, which, in fact, are losses and in that way had decreased percent of oil shale losses during extraction”.

The data in Table 12 illustrate the real losses of oil shale mined by underground and opencast methods over the last two years, when the writing off losses are especially high.

Table 12. Oil shale mining efficiency, taking into account written off reserves

Underground Mining	2001	2002
Extracted oil shale, 1000 tonnes	5,892	5,615
Oil shale losses according to the official data, 1000 tonnes	2,366	2,233
% of the losses [official] from the extracted oil shale	28.7%	28.5%
The volume of oil shale reserves, which were written off, 1000 tonnes	-6,017	-3,164
inc. overestimation of seam thickness, 1000 tonnes[4]	-259	-312
inc. overestimation of reserves, 1000 tonnes	-5,758	-2,852
inc. transfer of oil shale reserves into reserves of other mining field, 1000 tonnes	-20,674	0
inc. addition of oil shale reserves from reserves of other mining field, 1000 tonnes	20,674	0
The total losses [official + written off], 1000 tonnes	8,124	5,083
% of the total oil shale losses [official + written off] from oil shale extraction	58.0%	47.6%
The underestimation of the percent of oil shale losses, %	29.3%	19.1%
% of oil shale extraction from reserves (coefficient of extraction)	42.04%	52.48%
Oil shale total losses [official + written off] / extracted oil shale, times	1.34	0.91

Opencast mining	2001	2002
Extracted oil shale, 1000 tonnes	3,994	4,898
Oil shale losses according to the official data, 1000 tonnes	367	456
% of oil shale losses from the extracted oil shale, %	8.4%	8.6%
The volume of oil shale reserves, which were written off, 1000 tonnes	+17	+416
overestimation of seam thickness, 1000 tonnes	17	27
overestimation of reserves, 1000 tonnes	0	389

Taking into account written off oil shale reserves the picture of oil shale losses in underground mining changed significantly: 58% compared to the official 28.7% in 2001 and

[4] This number is not taken into account in the further calculation

47.6% compared to the official 28.5% in 2002. The energy value of extracted oil shale was 14.149 TWh in 2002; the energy value of oil shale losses was 5.640 TWh (according to the official data) and 12.85 TWh taking into account written off reserves.

Based on long-term mining experience the average excavation factor in underground mining is 50-60% and 80-90% in open cast mining, losses being about 55% and 15% correspondingly [Kattai V., 2003].

Table 13 illustrates the average efficiency of oil shale mining on the basis of official data from "AS Eesti Põlevkivi" and according to the average excavation factor, which was estimated by Kattai [Kattai V., 2003].

Table 13. Oil shale losses in the process of oil shale mining in 2002

	Official data of "AS Eesti Põlevkivi"			On the basis of long-term experience		
	Underground mining	Opencast mining	Total	Underground mining	Opencast mining	Total
Oil shale reserve, TWh	18.095	12.345	30.440	23.540	13.286	36.826
Net excavation, TWh	12.947	11.294	24.240	12.947	11.294	24.240
Losses, TWh	5.149	1.051	6.200	10.593	1.993	12.586
Losses, %	28%	9%	**20%**	40 – 50%	10 – 20%	**30%**

energy rating of oil shale – 8.3 MJ/kg

As seen from Table 13, according to the data of "AS Eesti Põlevkivi", 30.44 TWh of oil shale as an underground resource was consumed and 24.24 TWh of saleable oil shale was produced. Taking into account the long-term excavation factors, 36.83 TWh of oil shale resources were used.

The average losses of oil shale mining (TWh/TWh, tonne/tonne)

20%
official data of "AS Eesti Põlevkivi"

30%
according to the long-term geological experience

2.9.2. Oil shale losses in the process of enrichment

As it was noted above, the losses of oil shale in the process of oil shale enrichment do not exceed 5% (**P4**). In our calculations, the losses were taken to be 2.5%, which is 182 thousand tonnes of oil shale or 0.46 TWh in 2002.

2.9.3. Efficiency of electricity generation from oil shale

The next step after oil shale mining and enrichment is consumption by consumers – power stations. As it was noted, about 73% of oil shale was consumed for electricity production (**P6**), 8% was used for thermal energy production (**P6**), 17% of oil shale was used for conversion to other forms of fuels – shale oil (**P7**) [Energy balance 2002].

The total amount of oil shale consumed for electricity generation was 9,383 thousand tonnes in 2002 [Energy balance 2002]. The efficiency of electricity production varied between 8% and 29% (see also Chapter 2.8.1).

Table 14. Efficiency of electricity generation from oil shale

Oil shale used for electricity generation	**TWh**	**24.761**
Efficiency of electricity generation by Power Plants	%	28.3
Electricity generation by Power Plants	TWh	6.996
Self–use of electricity by Power Plants (from electricity generated)	%	11.5
Self–use of electricity by Power Plants (from electricity generated)	TWh	0.804
Net production of electricity by Power Plants from oil shale	**TWh**	**6.191**
Electricity transmission to consumers: Transmission losses	%	3.7
Electricity transmission to consumers: Distribution losses	%	11.9
Total electricity losses in network	**TWh**	**0.966**
Electricity consumption by end-users (consumers including Eesti Põlevkivi)	**TWh**	**5.225**
Electricity consumption by “AS Eesti Põlevkivi”	%	3%
Electricity consumption by “AS Eesti Põlevkivi”	TWh	0.157
Electricity consumption by other consumers –“real end-users”	**TWh**	**5.068**
The total efficiency of electricity production (from power plant to consumers outside of system)		**20.5%**

The efficiency of electricity generation was estimated by us as the weighted average of efficiencies of power plants (Appendix V).

The electricity use by power plants (self-consumption) was calculated using Eesti Põlevkivi’s data [Jostov M., et al., 2000].

The electricity losses in transmission grid and distribution grid were calculated as indicated in Eesti Energia’s annual report 2003/2004;

The electricity consumption by “AS Eesti Põlevkivi” was calculated using data from Appendixes of annual bookkeeping…, 2003 and price of electricity for large industrial users according to the Energy balance 2002 (see Appendix V).

The efficiency of ELECTRICITY production (input from power plants to consumers outside of the power plants, TWh/TWh)

20.5%

Taking into account the possible increase of efficiency after installing new Circulating Fluidised Bed boilers and replacing all the old boilers; the efficiency of electricity production (from power plants to consumers outside of the power plants) could increase to **24%.** Calculation based on unofficial data - oral communications by I. Aarna, A. Ansip – the efficiency of power generation with two new boilers is increasing to 32-34%. Assuming that 33% of the power is generated using the new boilers currently, the efficiency of electricity generation is about **22%**.

The total efficiency of electricity generation to the consumers outside the oil shale industry (taking into account also self-consumption of power plants and losses in the power distribution grid, see Fig. 32) was estimated at **14%.** With current installation of two new boilers, assuming that 33% of the power is generated using them, the overall efficiency should be about **16%.** After the installation of CFB boilers in Eesti PP and Balti PP, and replacing all the existing old boilers, the total efficiency could be increased maximally to **17%**. It should to remembered, that remarkably more than 20 billion EEK should be invested to achieve the noted increase in overall efficiency, and to keep the inefficient industry alive.

The efficiency of ELECTRICITY production (from oil shale mining to consumers outside of the oil shale industry, TWh/TWh)

14%

Taking into account the increase of efficiency of power generation after launching of new CFB boilers (unofficial data) the overall efficiency should be about

16%

Maximum increase in overall efficiency, which could be achieved by replacing all the existing old boilers by new CFB boilers, would be

17%

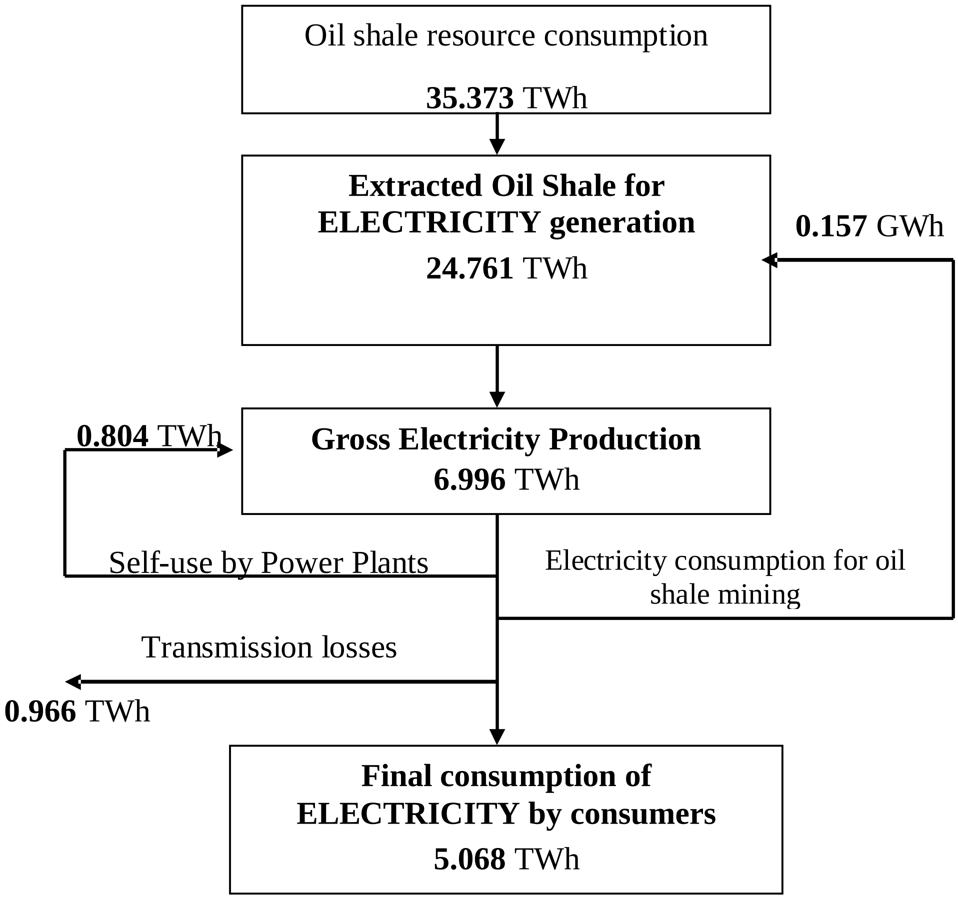


Figure 32. Flows of electricity from oil shale mining to consumers outside the system

2.9.4. Efficiency of thermal energy generation from oil shale

The total amount of thermal energy produced in 2002 from oil shale was 1.410 TWh (Fig. 25). 53% of the total heat was produced by Balti PP, and 7.7% by Eesti PP. Kohtla–Järve CHP and Ahtme CHP produced 0.555 TWh of thermal energy (17% and 22% of the total heat production in 2002). The efficiency of power plants varies from 44% to 68% (see also Chapter 2.8.1.).

The total consumption of oil shale for thermal energy generation, according to the statistical data, was 1,030 thousand tonnes [Energy balance 2002].

The calculated efficiency of production of thermal energy by oil shale power plants is presented in Table 15 and Fig. 33.

Table 15. Efficiency of thermal energy generation from oil shale

Oil shale consumption for thermal energy generation	**TWh**	**2.300**
Efficiency (weighted average) of heat generation by Power Plants	%	61.3
Thermal energy generated by Power Plants	TWh	1.410
Self-use of thermal energy by Power Plants	%	8.5
Self-use of thermal energy by Power Plants	TWh	0.1198
Net production of heat by Power Plant	**TWh**	**1.290**

Heat losses in networks	%	13.5
Heat losses in networks	TWh	0.174
Heat consumption by consumers including “AS Eesti Põlevkivi”	**TWh**	**1.116**
Heat consumption by “AS Eesti Põlevkivi”	TWh	0.011
Heat consumption by “AS Eesti Põlevkivi”	%	0.9
Heat consumption by end-users	**TWh**	**1.105**

The total efficiency of thermal energy production to end-users	**TWh**	**48%**

The efficiency of heat generation by power plants was estimated by us as the weighted average (see Appendix V).

The heat of self-use by power plants was calculated using literature data [Talve S., et al., 2001], where the heat self-consumption was presented for Ahtme CHP.

The heat losses in transmission network were estimated using data of Talve [Talve S., et al., 2001] and the database of SOE [www.stat.ee]. The losses in transmission network for Ahtme CHP, and the corresponding Estonian average were practically the same - 13.5% and 13% respectively.

The volume of heat consumption by “AS Eesti Põlevkivi” was estimated using the data on the total cost for heat from annual report of “AS Eesti Põlevkivi” and an average price of heat (see also Appendix V).

The efficiency of THERMAL ENERGY production (from power plant to consumers outside of the heat generation system)

48%

Taking into account also the mining losses, the final efficiency of thermal energy production from oil shale is 34%. Unfortunately, the data that would allow more detailed calculations of efficiency of thermal energy production, based on the characteristics of power plants - self-consumption and transmission losses from power plants to consumers, characteristics of oil shale used, etc. to be made were not available in published sources.

The overall efficiency of THERMAL ENERGY production from oil shale was calculated to be

34%

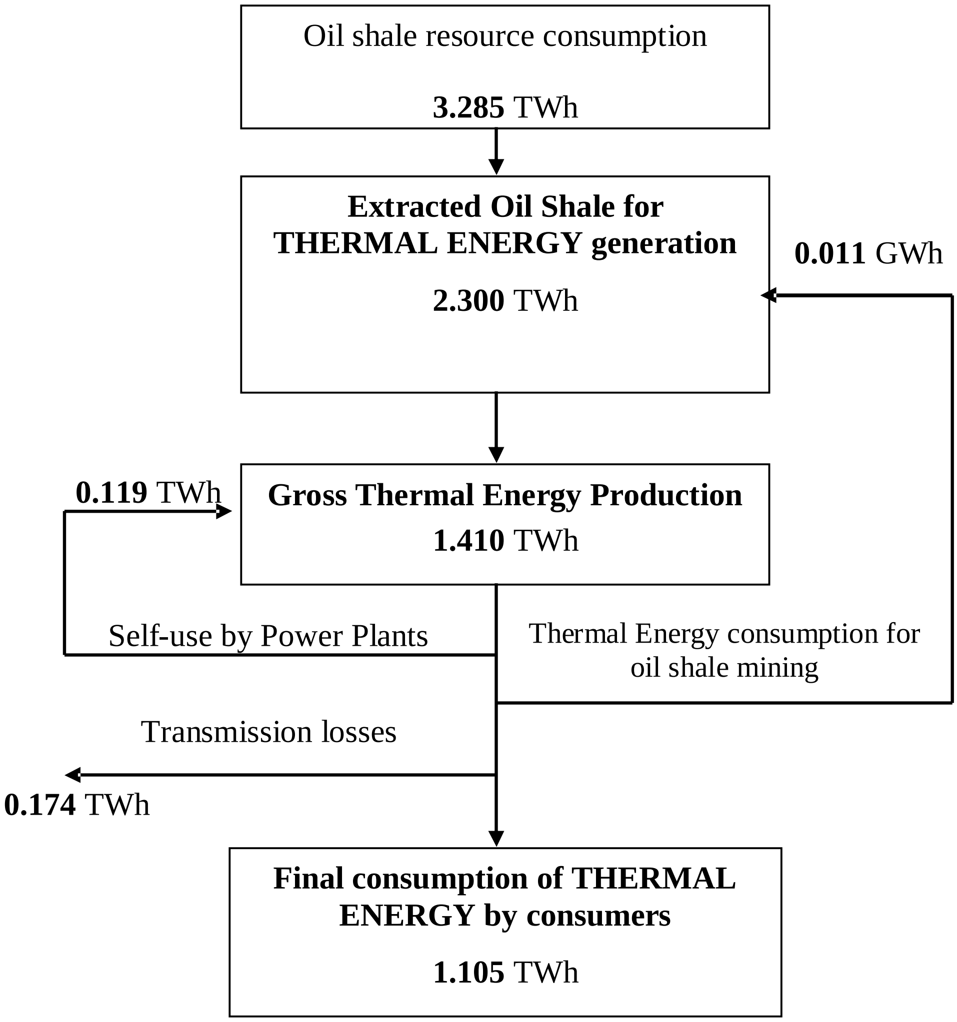


Figure 33. Flows of thermal energy from oil shale mining to consumers outside the system of thermal energy generation.

3. Natural resources and environmental impact of the oil shale industry

3.1. Atmospheric emissions

The kukersite chemical composition, the low calorific value of oil shale and the low efficiency of power plants determine the (large) impact of the oil shale industry on the environment – large volumes of emissions into the atmosphere.

About 65.6 thousand tonnes of SO_2, 10.2 thousand tonnes of NO_X, 25 thousand tonnes of particulates were emitted by Narva PP and Kohtla-Järve PP in 2002 (Table 16), which were 78%, 66% and 71% of the total atmospheric pollution from stationary sources in Estonia respectively. Emission of CO_2 from power plants was 9,433 thousand tonnes in 2002.

Table 16. Emissions - g per 1 kWh of energy [calculated on the basis of Eesti Energia environmental..., 2002]

	Narva PPs		Kohtla-Järve CHPs		Iru PP[5]
	Eesti PP	Balti PP	Kohtla-Järve CHP	Ahtme CHP	
SO_2	10.3	6.7	7.0	7.2	0.02
NO_X	1.2	1.3	0.6	0.5	0.49
Particulates	6.9	1.4	0.4	1.1	
CO			0.1	0.1	0.04
CO_2	1,091.3	1,199.6	535.2	581.9	248.8

Estonia and Finland concluded a cooperation agreement on air protection in 1993. The main issue of this agreement was "to reduce the spread of air contaminants and avoid the contaminants exceeding their critical loads on the territories of the Republic of Estonia and the Republic of Finland". The aim of this agreement was to reduce SO_2 emissions by at least 80% from the 1980 level by the year 2005.

According to Directive 2001/80/EC (on the limitation of emissions of certain pollutants into the air from large combustion plants) Narva PPs should meet the standards set for large combustion plants (Table 17).

According to Directive 2001/81/EC (on national emissions for certain atmospheric pollutants) the national emissions of SO_2, NO_X, VOC and NH_3 should not exceed 100 thousand tonnes, 60 thousand tonnes, 49 thousand tonnes and 29 thousand tonnes respectively by the year 2010.

Table 17. The maximum permitted values for emissions of contaminants into atmosphere [Estonia: Narva power...]

	EU Directive 2001/80/EC (new solid fuel plant of > 500 MW from 2002) mg/Nm^3	EU Directive 2001/80/EC (existing plant of > 500 MW from 2008) mg/Nm^3
SO_2	200	400
NO_x	200	500*
Particulates	50	50

* 200 from 2016

[5]Operating on natural gas

It is expected that emissions from the new CFB boilers will be within all the limits determined by the Directives and the agreement with Finland. Expected emissions from the new boilers are as follows: 200 mg/Nm^3 for SO_2 and NO_X and 30 mg/Nm^3 for particulates.

Actually, data of emissions from new boilers have not been published yet in official sources, but according to the estimations made by researchers before the launch, expected emissions will be as follows (Table 18, Table 19):

Table 18. Emissions from Balti PP and Eesti PP in 2001 and after renovation of power units, tonnes [Liblik V., et al., 2002]

	year	Balti PP	Eesti PP	Total Narva PPs
SO_2	2001	26,896	37,742	64,634
	2006[6]	3,631	34,387	38,018
	change	-23,265 (86%)	-3,355 (9%)	-26,616 (41%)
Particulars	2001	22,315	22,670	44,991
	2006	333[1)]	3,628[2)]	3,961
	change	-21,982 (98%)	-19,042 (81%)	-41,030 (90%)
NO_X	2001	3,483	6,545	10,028
	2006	1,522	6,530	8,052
	change	-1,961 (56%)	-15 (0.2%)	-1,976 (20%)
HCl	2001	528	774	1,302
	2006	356	1110	1,466
	change	172 (33%)	+336 (43%)	+164 (13%)
CO	2001			
	2006	1,090	958	2,048
	change	100%	100%	100%
CO_2	2001	2,990,610	6,320,373	9,310,983
	2006	1,713,670	6,166,230	7,879,900
	change	-1,276,940 (43%)	-154,143 (2%)	-1,431,083 (15%)
Oil shale consumption, million tonnes	2001	3,392	6,921	10,313
	2006	2,287	7,130	9,417
	change	-1,105 (33%)	+209 (-3%)	-896 (9%)

[1)]renovated power unit 30mg/Nm^3, 12 power unit – 100 mg/Nm^3
[2)]renovated power unit – 30mg/Nm^3, others - < 200mg/Nm^3 (75 mg/MJ)

The comparative data of emissions per kWh from Pulverized Firing Bed boilers and from Circulating Fluidized Bed boilers are presented in Table 19.

Table 19. Emissions into atmosphere from the PFB and CFB boilers, g/kWh [Arro H., et al., poster]

	PFB	CFB
SO_2	7.78	0.21
NO_X	1.23	0.61
Particles	3.72	0.13
CO	0.21	0.18
CO_2	1,300	1,050
HCl	0.35	

[6]2006 – after installation of new power units

As it was indicated above, Estonia is a world and European Union leader in CO_2 emissions (see also Chapter 1.1.). CO_2 emissions in power generation reach 1.2 tCO_2 / MWh or 1 tCO_2 per 1 tonne of used oil shale. CO_2 emissions with new CFB power units will be decreased to about 1 tCO_2 per MWh, which is not a great difference.

Burning of 1 t of oil shale is accompanied by emission of about 1 t of CO_2

To summarize the data presented on atmospheric emissions from oil shale power generation plants it should be noted that emissions of all important substances have been or could be reduced significantly with one exception – CO_2.

Indeed, as it is seen from Tables 18, 19, after installation of power units based on CFB technology with more efficient flue gas filters, the emissions have been, or could be reduced significantly:

§ SO_2 emissions – reduction by 95-97%
§ NO_X (NO_2) emissions – reduction by 50-55%
§ Particulate emission – reduction by 95-97%
§ CO_2 emission - reduction by 15-20%

These reductions would allow Narva PP to meet all the requirements of the EU Directives and the agreement with Finland.

According to “Annex B” of the Kyoto Protocol [Kyoto Protocol], Estonia must reduce emission of CO_2 by 8% by the year 2012 compared to the year 1990. Actually, CO_2 emissions are already 3 times lower compared to the year 1990 (from 31,787 Gg in 1990 to 10,389 Gg in 2003 [www.stat.ee] - oil shale production was 21.1 million tonnes in 1990 and 11.3 million tonnes in 2003). Estonia has the possibility to sell 62 million tonnes of “hot air” in 2005-2007 despite the fact that its CO_2 emissions per capita, per TPES and per GDP are one of the highest in the European Union, and the world (see Chapter 1.1.).

On the basis of the analysis carried out, it is obvious that continuation with the oil shale energy sector would not allow any significant reduction in CO_2 emissions and Estonia would need special status in the EU, and the world community of states. These circumstances should be taken into consideration seriously when designing the future of the Estonian energy sector in the post-Kyoto period.

3.2. Waste generation

The problems associated with a huge amount of waste generation are directly determined by the chemical composition of oil shale (see also Chapter 2.2).

The main types of wastes generated in the process of oil shale mining and consumption are:

§ Solid waste generated in the process of oil shale mining – host rock and waste after enrichment;
§ Oil shale ash generated in the process of electricity and heat production;
§ Semi-coke and fuse, and “black ash” generated in the process of shale oil production.

According to European Commission Decision 2000/532/EC (European Waste Catalogue and Hazardous Waste List), oil shale ashes, semi-coke and fuse are hazardous wastes.

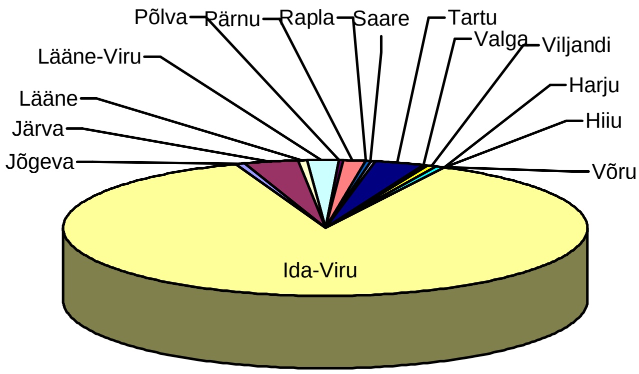


Figure 34. The structure of the amount of waste generated in the counties [Review of Estonian waste…, 2003]

About 80% of the total amount of waste generated in Estonia is generated in Ida-Viru county by the enterprises of oil shale processing - Fig. 34, Fig. 35, and Table 20:

Table 20. The total amount of non-hazardous and hazardous waste generated in Estonia [Review of Estonian waste…, 2003]

	2000, t	2001, t	2002, t	2003, t
Non-hazardous waste	5,618,972	6,632,752	7,998,566	10,856,031
…inc. rock heap (code 01 01 02)[7]	4,030,084	3,840,858	4,872,247	6,212,805
% from the total amount of non-hazardous waste	72%	58%	61%	57%
Hazardous waste	5,965,750	6,206,013	6,398,580	7,540,480
...including				
…semi-coke (code 05 06 97*)	1,007047	1,107 895	810,925	815,714
…fuse (code 05 06 98*)	8,359	14,336	18,528	19,718
…oil shale bottom ash (code 10 01 01 04*)	4,780,417	4,776,582	5,157,871	2,654,046
... oil shale fly ash (code 10 01 98*)	149,191	140,862	184,162	3,679,572
% of waste from oil shale industry from the total amount of Hazardous Waste	99.7%	97%	96%	95%

[7]Including rock heaps from mining of limestone, dolomite

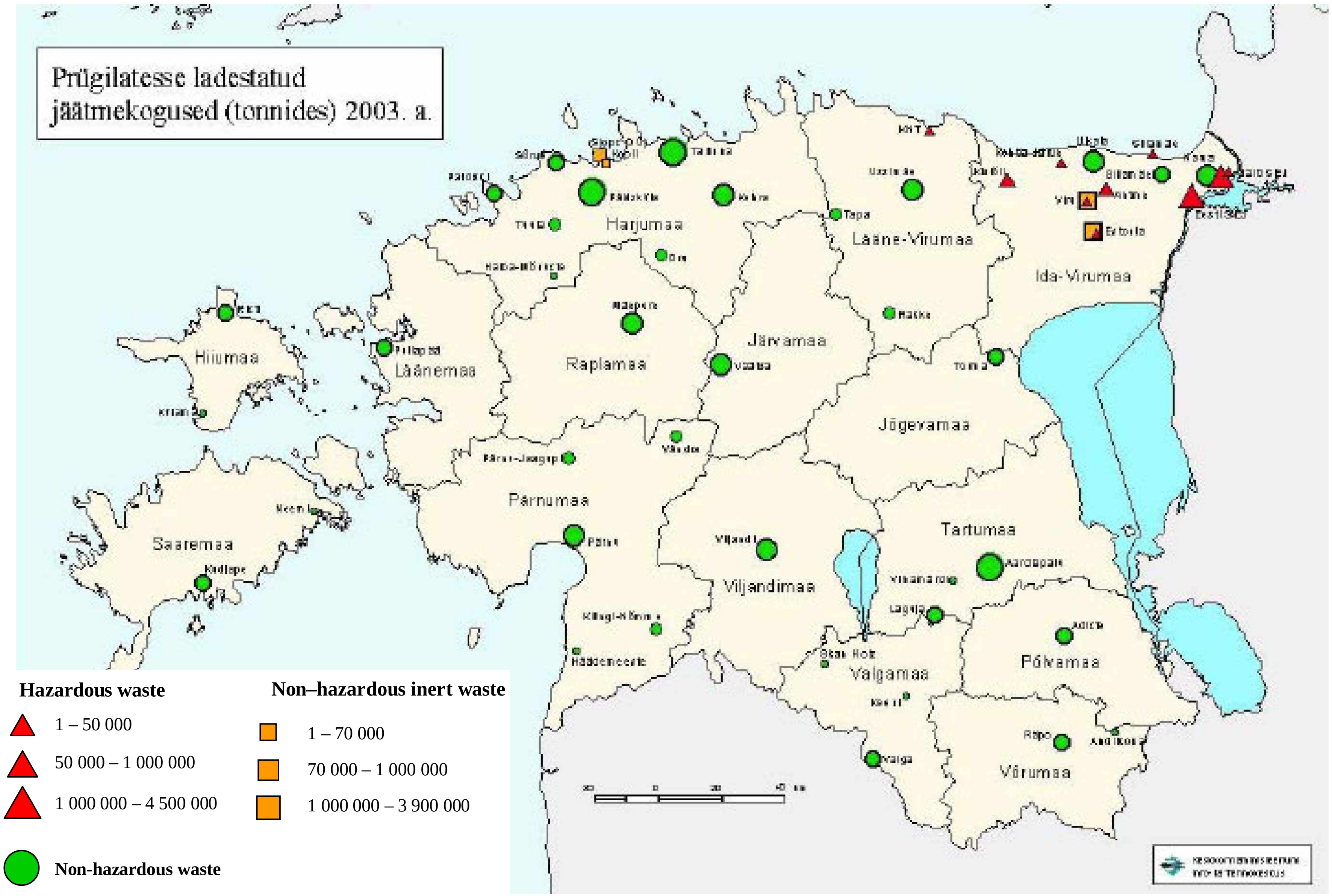


Figure 35. Location of landfills and waste quantities [Review of Estonian waste…, 2004].

3.2.1. Solid wastes of oil shale mining

The volume of waste generated in the process of oil shale mining depends to a great extent on the mining technology.

In opencast mining the waste is generated as the result of removing of covering layer, which has a thickness of 12 – 16 m. Peat, loam, loamy sand and clay are located in the upper part of the covering layer and rocky material, from limestone, marly limestone to marl, is found usually in the lower part. The average coefficient of overburden is 3.3 m^3 per tonne of extracted oil shale [Kikas V., 1988]. These materials are temporarily stored and used for quarry restoration. These wastes are not included in annual waste accounting reports, as they are reused for reclamation (Table 1 in Appendix VI) of land wrecked by mining (Fig. 36).

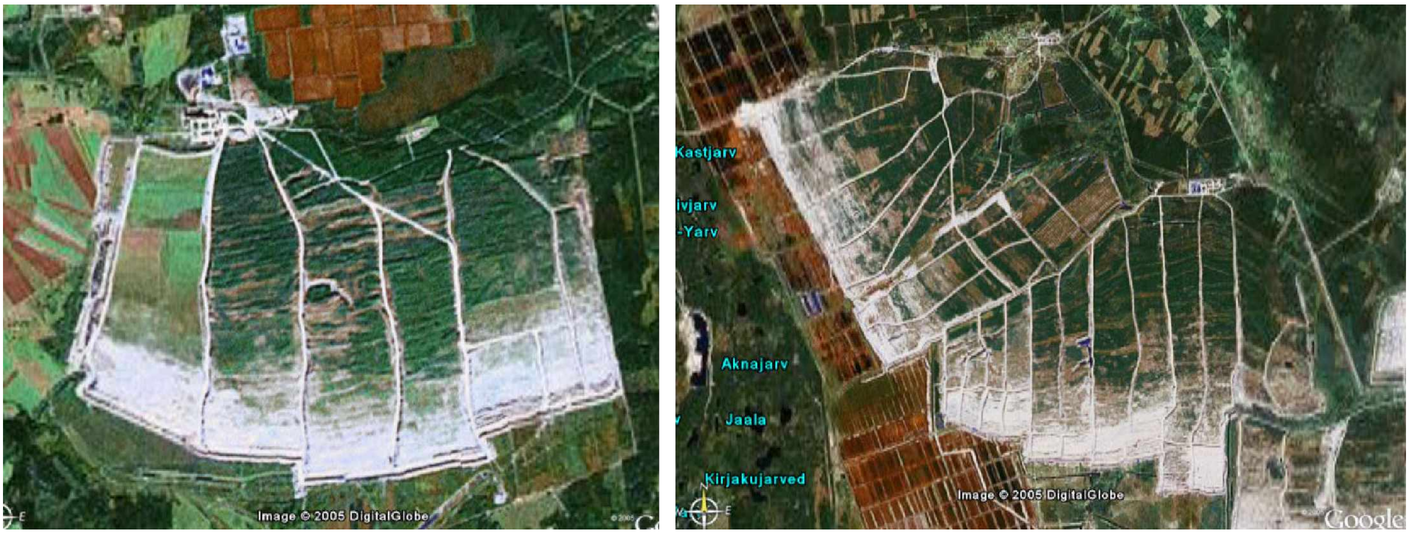


Figure 36. Aidu (left) and Viivikonna, Sirgala (right) open mines [Google Earth $59^0$19'25.33"N, $27^0$06'05.53"E and $59^0$17'09.64"N, $27^0$40'58.81"E].

0.5-0.6 tonnes of solid non-hazardous waste (waste code 01 01 02) per tonne of extracted oil shale is generated in the process of oil shale enrichment and is deposited in landfills:

Enrichment waste[8]
551.1 kg ⇒ **1 tonne**
Oil Shale

The waste contains 6 – 12% organic matter [Sørlie J.-E., et al., 2004]. The total volume of waste from oil shale mining is 94 million m^3 (165 million tonnes) and it covers more than 337 ha (Table 2 in Appendix VI) [Sørlie J.-E., et al., 2004]. The number of abandoned landfills was 29 in 2002, with an area of 158.8 ha and with 40.4 million tonnes of stored waste. The largest of them are Tammiku 3, Sompa 5 (4 million tonnes) and Tammiku 2 (4 million tonnes) [Treatment plan..., 2002]. The volume of waste on used landfills was 128 million tonnes in 2002: Estonia 1 (66 million tonnes), Ahtme 2 (29 million tonnes), Viru 3 (28 million tonnes) and Viru 2 (5 million tonnes) [Treatment plan..., 2002].

As it was noted waste from oil shale enrichment is not hazardous, but the concentration of organic matter in it represents a risk of self-ignition - self-ignition of 27% of all landfills (total **34 landfills** (Fig. 37)) have been observed.

[8]the data of 2002

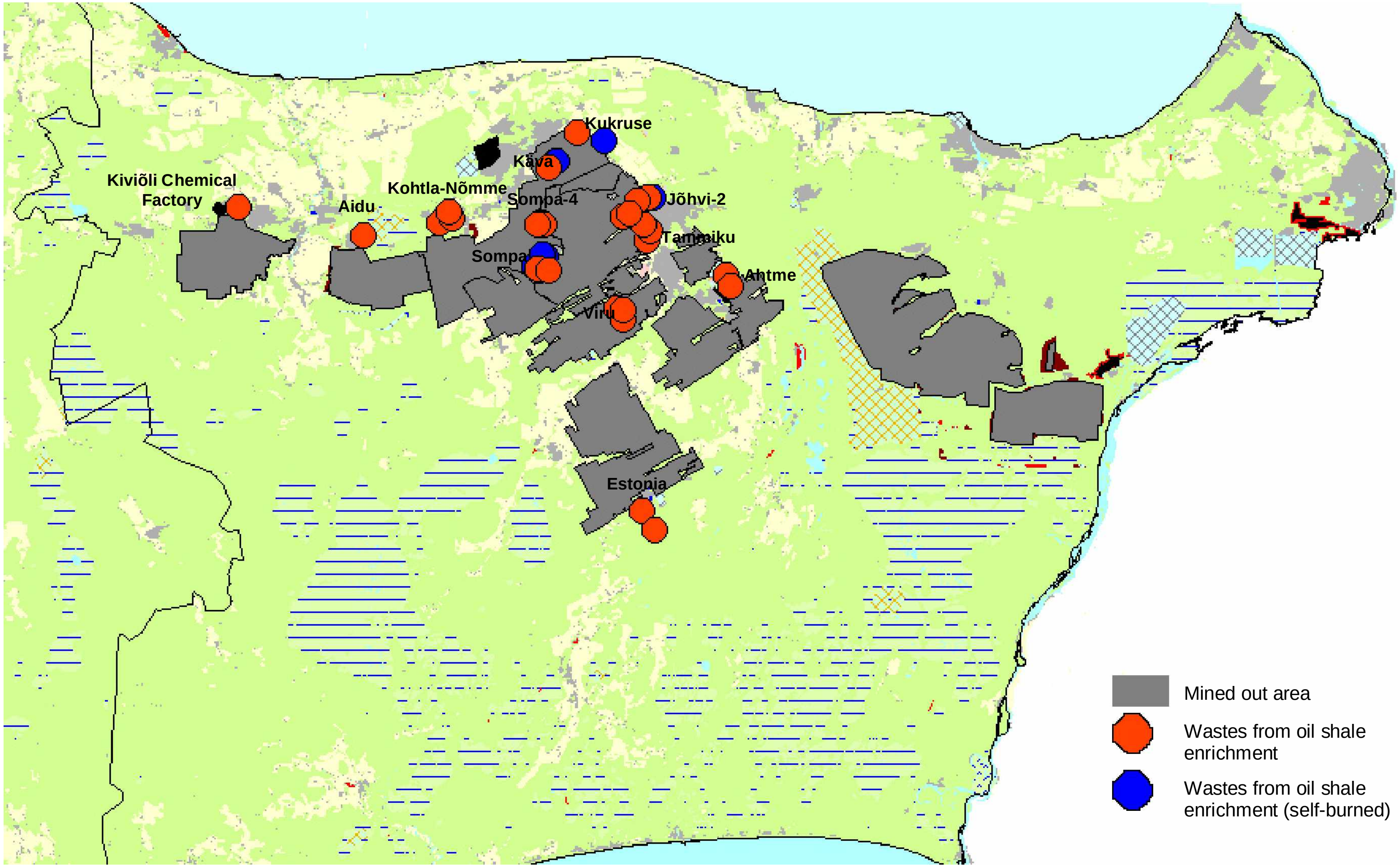


Figure 37. Wastes from oil shale enrichment [Sørlie J.-E., et al., 2004; Basic map]
See also Table 2 in Appendix VI

A recently burning landfill – Kukruse – was investigated by researchers from the Institute of Geology at Tallinn University of Technology and the Norwegian Geotechnical Institute on the initiative of the Norwegian Ministry of Foreign Affairs [Sørlie J.-E., et al., 2004].

The results of boring in Kukruse showed that the temperature inside the landfill changed from 63^0C at 2m to 96^0C at 23m depth. High temperature effects the organic composition of the waste [Sørlie J.-E., et al., 2004], and compounds dangerous to nature and human health are forming and leaching out, contaminating groundwater and soil.

The results of observation of groundwater and soil illustrate that the environment close to burning landfills is contaminated with molybdenum, copper, sulphate, arsenic, oil products and PAHs (Polycyclic Aromatic Hydrocarbons) [Narva power plants…]. The pH of leachate near burned landfill is 8.0 - 10.1.

The conclusion drawn by Sørlie [Sørlie J.-E., et al., 2004] was that, because of low mobility of the PAHs and other compounds in the leachate, these wastes would not pose a significant threat. However, it must be noted that eventually all the compounds leaching out of the enrichment waste landfills will end up in the groundwater, and needless to say the long term risks of these landfills have not been assessed properly.

3.2.2. Solid wastes of electricity and heat generation

Due to the high concentration of mineral matter in oil shale, more than 45% of burned oil shale generates oil shale ash (waste code 10 01 97*, 10 01 98*). About 0.6 tonnes of oil shale ash per MWh was generated in Narva PPs and 0.4 tonnes of ash per MWh in Kohtla-Järve CHPs in 2002 (Fig. 38).

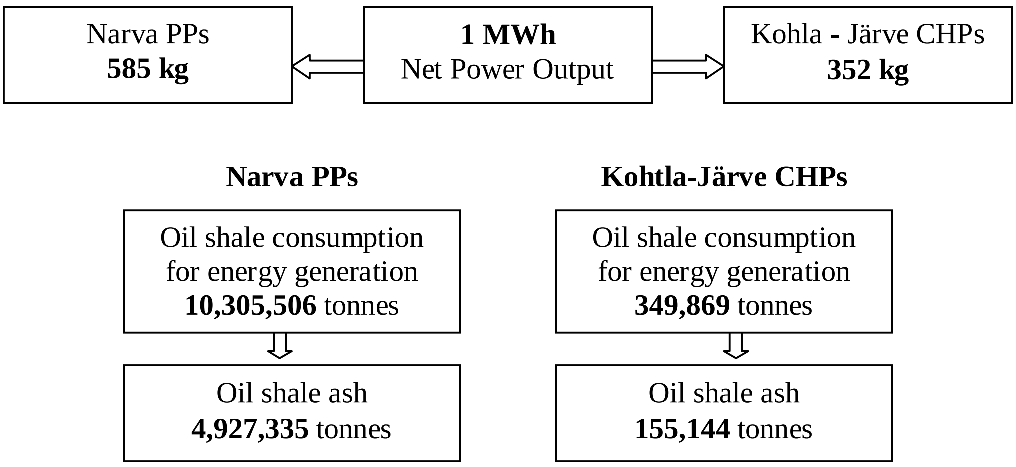


Figure 38. Oil shale consumption and oil shale ash generation by power plants, 2002 [Eesti Energia environmental…, 2002].

The mineral part of oil shale ash contains CaO (30-60%), SiO_2 (20-50%), Al_2O_3 (5-15%), Fe_2O_3 (2-9%), K_2O (2-6%), SO_3 (3.0-6.5%) and MgO (1-6%) [Laja M., 2005; Sørlie J.-E., et al., 2004]. Ash also includes a lot of heavy metals, among them highly toxic elements (see Table 4 in Appendix VI). The organic part of oil shale ash (< 1.5%) contains several polycyclic aromatic hydrocarbons (PAH): phenanthrene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)-and benzo(k)fluoranthenes, benzo(a)pyrene, etc [Laja M., 2005].

The total area used for the disposal of ash from **Balti PP**, including settling ponds, is 1055 ha (Ash-field No. 1 – 505 ha (settling pond is included) and ash field No. 2 – 550 ha (settling pond is included)), where about 148 million tonnes of oil shale ash is deposited (115 million tonnes and 32 million tonnes accordingly) [Treatment plan..., 2002]. The ash fields were created in 1959 and 1964-1987 respectively (Fig. 28). Oil shale ash is deposited close to the stations (into settling ponds), using water-ash-handling systems (the ration of ash to water is 1:13 [Prikk A., et al., 2004]).The volume of water in settling ponds of Balti PP is estimated at 8-9 million m^3 [Prikk A., et al., 2004].

The disposal area and ash volume stored on the landfills of **Balti PP**, according to Sørlie [Sørlie J.-E., et al., 2004] are 360 ha, 29,945 thousand m^3 of stored ash (Ash-field No. 1) and 400 ha, 34,036 thousand m^3 of stored ash (Ash-filed No. 2). As the volumes of stored ash on the landfills are different, we used the data from [Treatment plan..., 2002] in the further.

The ash disposal area of **Eesti PP** was created in 1969. The ash field consists of one settling pond with two ash sections - the area of the first ash section is 230 ha, and the area of the second section is 270 ha; the total area of the settling pond is 320 ha (Fig. 28, Fig. 39). The volume of ash stored fielding the ash field is estimated at 115 million tonnes of ash, and 3.5 million tonnes of semi-coke [Treatment plan..., 2002]. Oil shale ash is deposited close to the stations, using water-ash-handling systems also. The volume of water in settling ponds of Eesti PP is estimated at 7.5-10 million m^3 [Prikk A., et al., 2004].

The area of ash-disposal field of **Eesti PP** and the volume of stored ash, according to the data of Sørlie [Sørlie J.-E., et al., 2004] is 500 ha and 43,975 thousand m^3.

Figure 39. The ash disposal area of Eesti Power Plant [www.spordilinn.ee/idaviru].

The ash-disposal field of **Kohtla-Järve CHP** was created in 1949, and consists of nine sections (65.09 ha) and three settling ponds (6.56 ha), in which about 11 million tonnes of oil shale ash is stored. The ash disposal field of **Ahtme CHP** was created in 1949 and includes four sections (52.37 ha) and two settling ponds (3.08 ha); about 9 million tonnes of oil shale ash is deposited there [Treatment plan..., 2002].

The total area used for the disposal of oil shale ash, with settling ponds, is up to 2000 ha, which is 0.6% of the total territory of Ida-Viru county or 0.04% of the total Estonian territory.

According to Directive 1999/31/EC on the landfill of waste, from 17 July 2009, “liquid waste and waste which, in conditions of landfill, is explosive, corrosive, oxidizing, highly flammable or flammable” (Article 5 Paragraph 3 Item a, b) are not acceptable in landfills. Oil shale ash is classified as hazardous waste [Directive 91/689/EEC, Decision 2000/532/EC]. Thus, by 2009, new ash removal systems must be harnessed in the Narva power stations. Currently, new possible technologies for the treatment of ash in agreement with the requirements of the Directive are being considered by the management of Narva PPs, however, a solution has not been found (yet?).

According to the results of environmental monitoring of landfills carried out by Sørlie [Sørlie J.-E., et al., 2004], the pH of ash leachate is about 12.4 – 12.7, and the leachate is highly toxic. The leachate from ash contains also high levels of Al, Si, Ga, Na, Li, Cs, Rb, Co, Mn, V and Zn [Sørlie J.-E., et al., 2004]. The high alkalinity of leachate water, its toxicity and the concentration of hazardous substances result in the contamination of the soil and surface water. The soil contamination may also be a result of wind erosion from landfills and smokestacks, as shown by Sørlie [Sørlie J.-E., et al., 2004]. The contamination of soil by As, Cd and Pb was found in the northern part of the territory of Narva power stations (in the prevailing downwind direction). Concentrations of Zn, Cu, Mn, Cd and Ba exceeding the permitted limits were observed in the roots of plants close to Narva power stations.

According to the hydrogeological modeling carried out by Vallner [Sørlie J.-E., et al., 2004], the total inflow into the ash landfills is 13,700 m^3/day, about 15% of which flows directly into channels around the ponds, 85% is draining into the Quaternary deposits and Ordovician carbonate bedrock, and only 200 m^3/day flows into the underlying Ordovician – Cambrian aquifer. The ash leachate pollutes the water of Quaternary deposits and Ordovician carbonate bedrock beneath the ash plateau [Kivit N., 2004]. This is proved by the high content of sodium (1000 mg/l), chlorine (418 mg/l), and sulphate (541 mg/l) in the leachate. Moreover, the groundwater beneath the landfill contains up to 0.26 mg/l of oil products and up to 0.0062 mg/l of phenols. The concentration of toluene was up to 2.6 µg/l and xylene – 0.4µg/l. These organic pollutants could originate from the water of channels surrounding the landfill. In 2003 the channel water contained 0.1 mg/l of oil products, up to 0.1 mg/l of phenols, and PAH – 0.17 µg/l [Kivit N., 2004]. The polluting impact of ash leachates and organic substances, which have accumulated in the Ordovician carbonate bedrock, is revealed in water of the Ordovician-Cambrian aquifer system. An increase in the sodium content was detected in springtime, and concentrations of toluene and xylene were reaching 0.4 µg/l and 0.9 µg/l, respectively. The content of phenols was 0.0019…0.0034 mg/l [Kivit N., 2004].

An environmental audit was carried out in Narva power plants in 2001: the unloading area for start-up fuel oil, the area adjacent to the lubrication and transformer oil tanks, and the area around the industrial landfills were inspected [Narva power plant…, 2001]. The results of this monitoring showed that soil close to Eesti PP was contaminated with mineral oil (the permissible levels were exceeded 10 – 20 fold) and phenols (4-7 times higher than Estonian permissible levels). Contamination of the perched groundwater close to the power plant with mineral oil and PAH, and heavy pollution with petroleum was also observed. The soil and perched groundwater close to UTT-3000 shale oil refinery were contaminated with mineral oil, volatile organic compounds (VOC, the highest concentration exceeded the permissible level over 400 times over). Perched groundwater was polluted with PAH compounds, phenantrene, anthracene, benzo(a)pyrene. The contaminations of soil and perched groundwater close to Balti PP were similar to the contaminations around Eesti PP: mineral oil, PAH compounds, phenol. These contaminations require sound investments for the removal of negative impacts to the environment.

A comprehensive long term risk assessment of the ash fields' environmental impact should be carried out.

3.2.3. Wastes from chemical industry (production of shale oil)

The two main types of waste generated in addition to the "black ash" in the process of shale oil production: semi-coke and fuses, are both, according to Commission Decision 2000/532/EC, hazardous wastes.

About 3 tonnes of semi-coke (waste code 05 06 97*) and 68 kg of fuse (waste code 05 06 98*) are generated per one tonne of shale oil on average. About 811 thousand tonnes of semi-coke and 18 thousand tonnes of fuses were generated by the chemical industry in 2002, 22% of the generated volume of semi-coke and 0.5% of fuses were stored in landfills.

Semi-coke **2.9 tonnes**	⇐	**1 tonne** Shale Oil	⇒	Fuse **67.4 kg**

The semi-coke disposal areas are located close to Kohtla-Järve, Kiviõli and Narva towns; the total disposal area of semi-coke is about 248 ha, where 96 million tonnes of waste is stored (Table 21). Fuse waste was stored together with semi-coke until 1970, thus, according to the data of Kattai [Kattai V., 2003] the disposal area and the amount of waste are underestimated. The total area of fuse lakes is 1.55 ha, where about 140 thousand tonnes of fuse is thought to have been stored. The depth of fuse lakes is about 7 – 10 m; currently the fuse lakes do not meet environmental requirements (Fig. 40).

The area of landfills under semi-coke waste, according to the data of Sørlie, is 175.4 ha, the total stored volume of semi-coke is 83,367 thousand m^3 [Sørlie J.-E., et al., 2004] (see also Table 3 in Appendix VI).

Another source of data – Treatment plan of Ida-Viru county [Treatment plan…, 2005] – presents the data of semi-coke landfills area and stored volumes, which are 222 ha and 92,996 thousand tonnes stored wastes (see Table 3 in Appendix VI). As the data are dissimilar from different sources, we used the data of Kattai (Table 21) in the further calculation.

Table 21. The volume and area of landfills from shale oil processing [Kattai V., 2003]

	Type of waste	Area of landfills, ha	The volume of waste stored in landfills, million tonnes
Kohtla-Järve	Semi-coke	157	71
	Fuse	1.3	0.08
Kiviõli	Semi-coke	91	25
	Fuse	0.25	0.06

The mineral part of semi-coke mostly contains CaO (28 – 29%), SiO_2 (18 – 25%), CO_2 (7 – 15%); also Al_2O_3, Fe_2O_3, MgO, P_2O_5, S, Na_2O, K_2O, TiO_2, MnO are present. The organic part forms 9 – 16% [Otsa E., et al., 2003].

Semi-coke contains the following environmentally hazardous compounds: cancerogenic polyaromatic hydrocarbons (2.6-9.8 mg/kg), water soluble salts, where sulphides are the most dangerous (0.3-1.1 g/kg) and the organic part of semi-coke, which may cause the self-ignition of semi-coke [Otsa E., et al., 2003].

The semi-coke is characterized also by the highest content of Ag, As, Ba, Ce, Co, Eu, Ga, Gd, Ho, La, Mn, Mo, Nd, Ni, Pr, Sb, Sc, Sm, Th, Tm, V, Y and Zn (see Table 4 in Appendix VI). The concentration of phenols in fresh semi-coke is 9.40 mg/kg (semi-coke from Kohtla-Järve), the content of phenols in oldest semi-coke landfills is 0.01 mg/kg, which is less than the analytical detection limit [Sørlie J.-E., et al., 2004]. The concentration of PAHs varies from 3.90 to 4.47 mg/kg - in the fresh semi-coke the content is lower. According to another source, the concentration of PAHs varies from 8.17 to 13.34 mg/kg [Otsa E., et al., 2003]. The PAH are represented practically by the full spectrum of studied PAH compounds: Acenaphthen, Fluoren, Phenanthren, Anthracen, Fluoranthen, Pyren, Benzo[a]anthracen, Chrysen, Benzo[b]fluoranthen, Benzo[k]fluoranthen, Indeno(123-cd)pyren, Benzo[ghi] perylen [Sørlie J.-E., et al., 2004]. Ecotoxicological investigation showed that the semi-coke waste is toxic, very toxic and extremely toxic [Sørlie J.-E., et al., 2004].

A large amount of leachate is formed in the process of infiltration of precipitation – more than 30 – 40% of precipitation on the territory of landfills infiltrates. The pH of the leachate varies from 8.47 to 12.54; the concentration of Total Organic Carbon (TOC) varies from 12 to 14% (it depends on the age of landfills) [Otsa E., at al., 2003]; a higher concentration increases the probability of self-ignition of semi-coke. In accordance with Directive 2003/33/EC the value of TOC should not exceed 6% and pH should be maintained in the range 7.5-8 (Directive 2003/33/EC, Item 2.4.2).

The semi-coke leachates doubtless have contaminated water of the Ordovician carbonate bedrock beneath and in the vicinity of landfills in **Kiviõli**. The TDS varies between 890…2,730 mg/l [Sørlie J.-E., et al., 2004]. Alkalinity reaches 3,514 mg/l and pH up to 12.8. Electric conductivity is 2,295…15,130 µS/cm and increased concentrations are observed for Al, As Be, Br, Ce, Cd, Cl, Cr, Cs, Fe, Ga, K La, Li, Mo, Nb, Nd, Ni, P, Rb, S, Se, Sn, V, W, and Y in comparison to their natural levels. In one well the concentration of phenol was 2,032 mg/l, 2.4+2.5-dimethylphenol – 235 mg/l, 2+3-methylphenol – 2,313 mg/l, and 4-methylphenol – 183 mg/l. These values exceed the permissible level value (PLV). The spectrum of PAH is represented by benzo(a)anthracen, benzo(b)fluoranthen, benzo(k)fluoranthen, benzo(a)pyren, chrysen, fluoranthen, indeno(123-cd)pyren, and pyren, but the maximum sum of PAH reaches only 0.561 mg/l. In the Ordovician-Cambrian aquifer system, the chemical composition of water is mainly close to the natural. However, in one well the TDS of water was 1943 mg/l, the concentration of Ba, Fe, K, Mg, Na, and Sr were on average three times higher, and the content of Br, Cl, and Rb – six to ten times higher than in other wells. This demonstrates the existence of a contact between the overlying Ordovician aquifer system and the Ordovician-Cambrian aquifer system at this point.

Figure 40. Storage fields of fuse and semi-coke [Kattai V., 2003].

The channel water near the landfill of **Kohtla-Järve** contained extremely high concentrations of PAH, BTEX, and phenols; it was extremely toxic too [Sørlie J.-E., et al., 2004]. The Ordovician Lasnamäe-Kunda aquifer, which underlies the landfill, is sporadically polluted. In two wells the PAH values were higher than PLV in Estonia. The content of BTEX was up to 220…350 µg/l. Ordovician groundwater contains a large spectrum of phenols, but the most hazardous, mobile and chemically active groups of them (2,3-dimethyl-, 2,6-dimethyl-3,4-dimethyl-, and 3,5-dimethyl-phenols) prevailed. In deep layers of the

Lasnamäe-Kunda aquifer, the content of phenols many times exceeded the PLV. The water of the Ordovician-Cambrian aquifer contained BTEX, mostly benzene, toluentoluene, ethylbenzene, m+ρ-xylene, and o-xylene. All BTEX values measured were less than PLV. At a point near the landfill the concentration of phenols reached 2,027 μg/l.

The surface water close to Kiviõli was characterized as „very contaminated" [Sørlie J.-E., et al., 2004], because the content of all the heavy metals exceeded the permissible limits (PLV). The analysis of the leachate at Kohtla- Järve revealed high concentrations of phenols, PAH and BETX, which drain to the surface water system. Also the high concentration of As, Cu, Hg, Mo, Pb, U and Zn was noted in the upper layer of the soil close to the landfill areas (Kiviõli and Kohtla- Järve).

3.2.4. Summary of solid wastes generation and land use for their deposition

The amounts of wastes generated up to now are presented on Fig. 41, the total values of elements contained in wastes are presented in Table 22, Table 23.

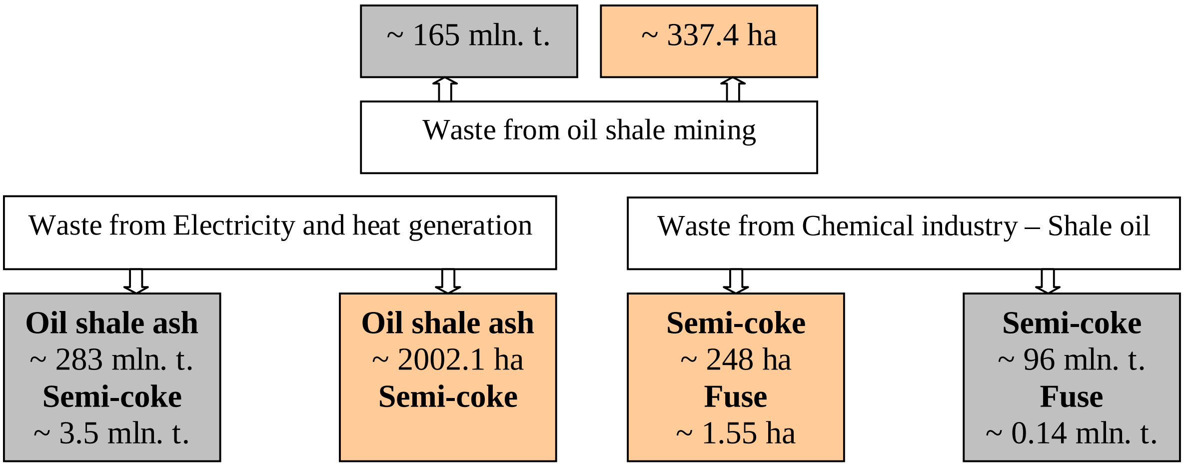


Figure 41. Summary of waste generation from oil shale industry.

These huge amounts of wastes pose a considerable long term threat to the environment in the region, also it is important to take into account that wastes from oil shale enrichment could self-ignite, thereby pollute environment around.

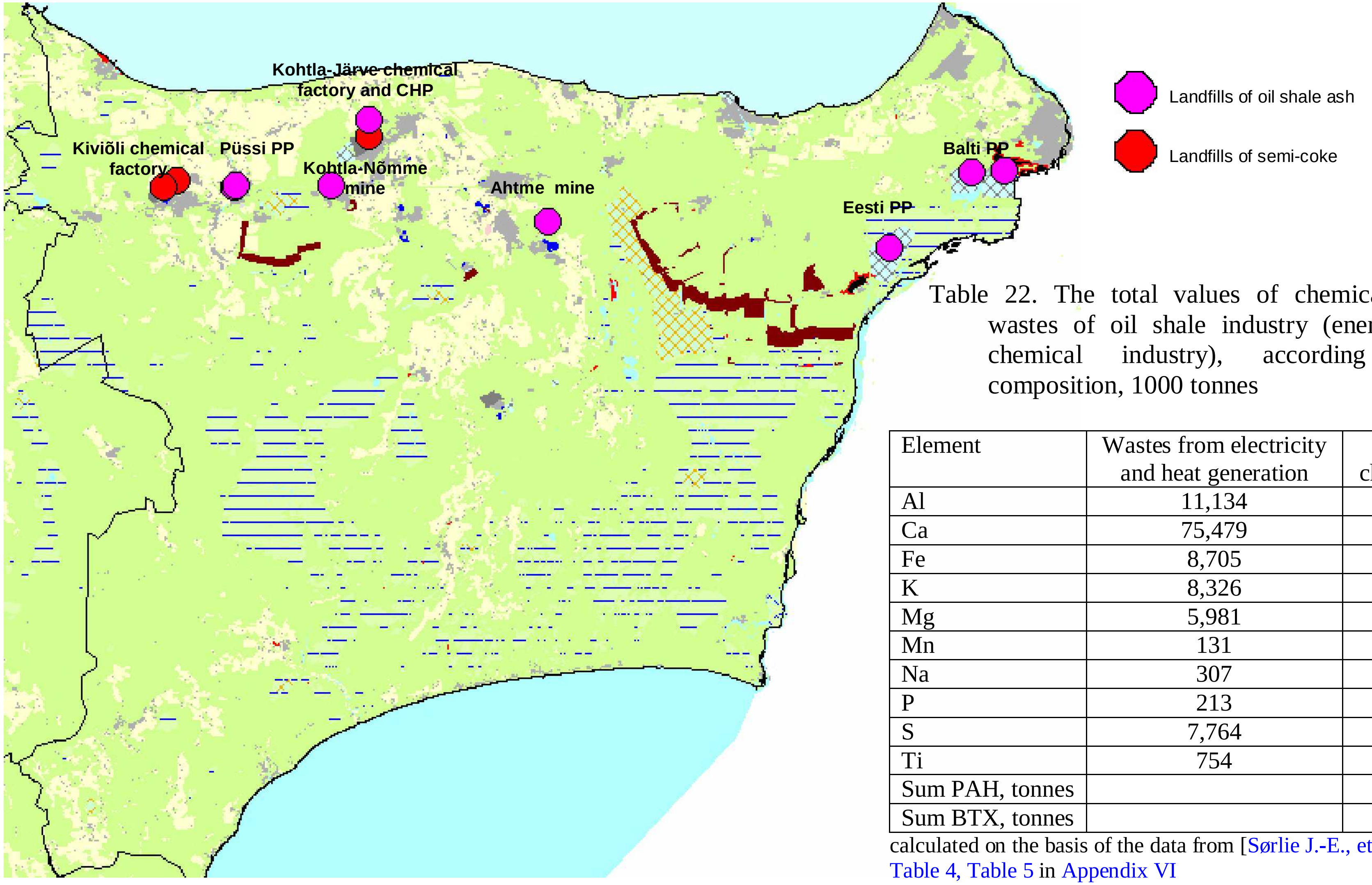


Table 22. The total values of chemical elements in wastes of oil shale industry (energy generation, chemical industry), according to wastes composition, 1000 tonnes

Element	Wastes from electricity and heat generation	Wastes from chemical industry
Al	11,134	2,530
Ca	75,479	18,893
Fe	8,705	2,698
K	8,326	1,740
Mg	5,981	1,205
Mn	131	29
Na	307	62
P	213	42
S	7,764	1,454
Ti	754	151
Sum PAH, tonnes		102.088
Sum BTX, tonnes		6.154

calculated on the basis of the data from [Sørlie J.-E., et al., 2004] see also Table 4, Table 5 in Appendix VI

Figure 42. Location of disposal areas of oil shale ash and semi-coke landfills [Sørlie J.-E., et al., 2004; Basic map]

Table 23. The total values of chemical elements in wastes from oil shale industry (energy generation, and chemical industry), according to wastes composition, tonnes

Element	Tonnes	Element	Tonnes	Element	Tonnes
Ag	37	As	8,114	Au	38
Ba	63,256	Be	377	Bi	40
Cd	66	Ce	12,997	Co	2,045
Cr	19,219	Cs	2,082	Cu	3,721
Dy	994	Er	482	Eu	245
Ga	3,996	Gd	1,058	Hf	674
Ho	144	La	9,193	Li	8,031
Lu	68	Mo	2,492	Nb	2,564
Nd	6,298	Ni	9,565	Pb	23,619
Pr	1,651	Rb	29,436	Sb	1,498
Sc	2,118	Sm	1,315	Sn	590
Sr	113,046	Tb	193	Te	3
Th	2,935	Tm	68	U	1,462
V	16,242	W	553	Y	5,762
Yb	597	Zn	23,139	Zr	25,435

calculated on the basis of the data from [Sørlie J.-E., et al., 2004] see also Table 4 in Appendix VI

3.3. Post-technological processes of oil shale mining and land use

One of the major dangers from oil shale mining is from post–technological processes on mined areas. The damage to the territory directly depends on the mining technology and is mainly connected with the flooding of the mines, changes in relief, and the formation of huge potentially unstable cavities, eventually filled with (polluted) groundwater (Table 5, Table 6 in Appendix VI). The mined out areas are classified as persistent, subsidence, stable and quasistable. The definition of these areas (Table 24) has been given by Reinsalu [Reinsalu E., at al., 2001].

Table 24. Restrictions to land use and building on the mined areas [Reinsalu E., at al., 2001].

Type of land	Building	Use in agriculture or forestry
Persistent	No restrictions	
Stable	Building of light constructions is permissible	No restrictions
Induced subsidence	Possibility and extent of additional subsidence unknown.	Possible changes of the moisture regime, depending on the composition of quaternary deposits.
Quasi-stable	Building is forbidden, permissible only by way of exception using specified blueprints.	Possible damage to vegetation, especially in the cases of unfavourable composition of quaternary deposits.

According to the data presented in Table 6 (Appendix VI), about 31% of the total mined out area is classified as subsidence, only 13% of the mined out territory is stable, and 53% is unstable, 79% of which is liable to subside in the next decades.

About 600 million tonnes of commercial oil shale has been removed from the ground in Ida-Viru county. It has left behind caves of more than 400 million m^3, which have been partially flooded during the years after the abandonment of the mines (see Fig. 10). It has been estimated that there is about 160 million tonnes of (polluted) groundwater in the abandoned caves, which are spread over almost 300 km^2. In these water-filled caves a slow but sure "dissolution" of pillars is taking place, and we can only imagine what will happen when the tens of km^2 of surface will fall down, with possible generation of hydraulic shock(s), in the 22nd century [Adamson A., et al., 2000].

Figure 43. Examples of post-technological processes [Valgma, I Geotechnical…].

3.4. Water resources of Northeast Estonia and impact of oil shale industry

3.4.1. Hydrogeological setting and natural water budget of the regional water resources

The area under consideration covers 5,015 km^2 in the Pandivere Upland, North-Kõrvemaa, Coastal Lowland of the Gulf of Finland, Viru Plateau, and Alutaguse Lowland [Arold I., 2005], (see also Fig. 44, Fig. 45, Table 25). The mostly flat Upland rises 70-130 m a.s.l. Plateaus have predominantly a slightly dissected topography, with absolute altitudes 40-75 m. Elevations of the Alutaguse Lowland are usually 30-45 m, and on the Coastal Lowland, between 0-30 m. Valgejõgi, Loobu, Selja, Kunda rivers, etc. flow northward from the Pandivere Upland. The local Jõhvi watershed is located between Kukruse and Pagari, where the absolute heights are 60-75 m. From this watershed, the surface water flows westward to tributaries of Purtse River and in southern and eastern directions to the channel network of Pungerja and Tagajõgi rivers. Another local watershed, the meridional Illuka kame field, lies 6-8 km eastward from the Jõhvi watershed. The surface water of the kame field partly flows into Vasavere River and partly into the left-bank network of the Narva River.

The Quaternary aquifer system (Q) consists mostly of glacial till that has been covered in places by glaciolacustrine sand, sandy loam, varved clay or glaciofluvial sand and gravel. In boggy areas, the uppermost portion of Quaternary deposits is represented by peat. The thickness of the Quaternary cover varies usually between 0.3-5 m. However, several ancient submeridional valleys with a depth of up to 70 m and buried by Quaternary sediments pass through the study area. One of them, the Vasavere buried valley, filled with sands and gravels of high hydraulic conductivity underlies the Illuka kame field. Water table conditions prevail in Quaternary deposits.

Southward from the North-Estonian Klint, the Quaternary cover lies predominantly on the outcrop of the Silurian-Ordovician aquifer system (S-O) consisting of fissured limestones and dolomites interbedded with marls. Their total thickness ranges from 10-20 m on the Klint and up to 170 m in the Pandivere Upland. The upper part of the carbonate bedrock is significantly karstified and cavernous to a depth of 30 m from its surface. Fissurization decreases in a downward direction, and deeper than 80-100 m from the bedrock surface the carbonate strata turn into the Silurian-Ordovician aquitard of regional extent. Therefore, the lateral hydraulic conductivity of the upper part of the carbonate bedrock is high or very high in the range 5-500 m/d but the lateral conductivity of the lower part does not usually exceed 0.1-1 m/d [Riet K., 1967]. The clayey interbeds with transversal conductivity of 10^{-5}-10^{-2} m/d serve as aquitards, dividing the carbonate bedrock into several local aquifers [Jõgar P., 1983; Vallner L., 1980].

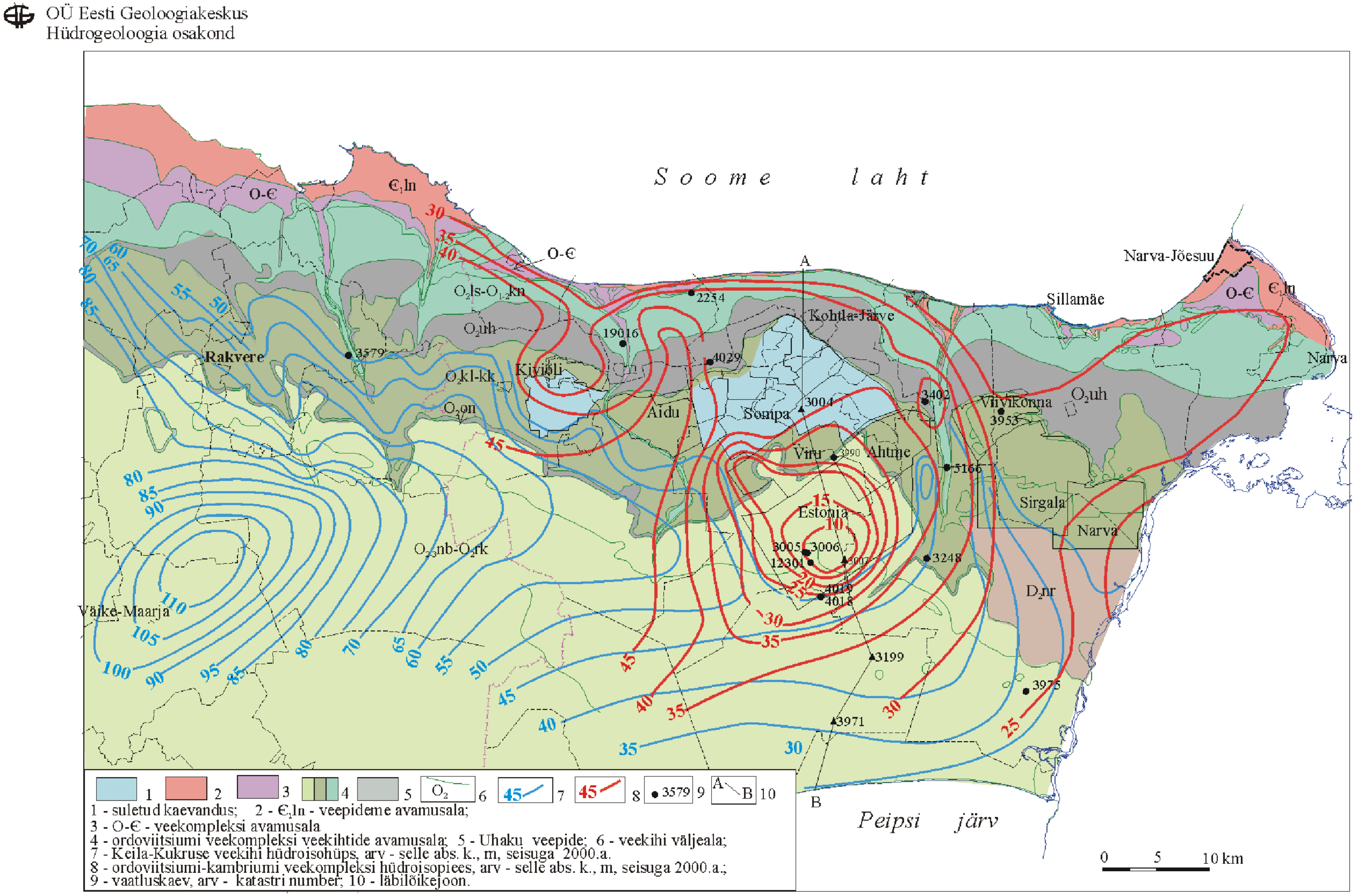
The Oandu Stage (O_2On), represented chiefly by 1-4 m-thick marl, is the uppermost effective aquitard in the carbonate bedrock [Vallner L., 1996a; Vallner L., at al., 1997; Perens L., 1998]. The Oandu aquitard is overlain by the Pirgu and Nabala-Rakvere (O_3Nb-O_3Rk) unconfined aquifers consisting of fissured limestones and dolomites. Their thickness grows from zero at the outcrop of the Oandu aquitard to 90-100 m at the southern border of the study area. The Uhaku Stage (O_2Uh), containing clayey interbeds in limestones, forms the next efficient aquitard of the carbonate bedrock. The Uhaku layers are under the water-table conditions at their outcrop. Between the Oandu and Uhaku aquitards lies the Keila-Kukruse aquifer (O_2Kl-O_2Kk) consisting of fissured limestones and dolomites. This aquifer, having a thickness of up to 35 m, is only halfway confined by the semipervious Oandu aquitard. Limestones between Uhaku aquitard and the Silurian-Ordovician regional aquitard form the Lasnamäe-Kunda aquifer (O_2Ls-O_2Kn) with a thickness of up to 35-40 m. In a restricted area at the Narva River, occurs the Narva aquifer (D_2Nr) consisting of Devonian dolomites and siltstones overlying the Ordovician strata.

Below come the Ordovician-Cambrian aquifer system (O-Є), having an average thickness of 20 m, and the Cambrian-Vendian (Є-V) aquifer system, with a thickness of up to 80 m. These aquifer systems consisting mostly of sandstone with siltstone interbeds are separated by the Lükati-Lontova regional aquitard ($Є_1Lk$-$Є_1Ln$). The Cambrian-Vendian aquifer system, including the upper, Voronka aquifer (V_2Vr), the lower, Gdov aquifer (V_2Gd), and the intermediate, Kotlin aquitard (V_2Kt), crops out along the northern coast of Estonia on the bottom of the Gulf of Finland. The depth of the crystalline basement (PR_{2-1}) from the ground surface increases from 150 m on the seashore to 350 m in the Pandivere Upland.

The annual precipitation varies between 700-760 mm/year and the annual evapotranspiration from the ground surface is mostly 400-500 mm/year in the study area [Resursy poverhnostnyh…1972]. In the central part of the Pandivere Upland, where the carbonate bedrock is most intensively karstified, the net infiltration rate (actual long-term groundwater recharge) reaches 280 mm/year or 9 l/(s·km^2) [Vallner L., 1980]. In this area almost all rain and thaw water percolates into karst interstices. Due to the high permeability of the carbonate bedrock, the groundwater formed discharges quickly to adjacent streams. Therefore, the groundwater table is relatively deep in the Upland, lying often 7-20 m below the ground surface. At such depth of groundwater, evaporation from the zone of saturation or capillary fringe is insignificant. Thus, the rivers with catchments in the central part of the Upland are under most favorable recharging conditions. For this reason, the mean specific runoff coefficient of the Kunda River is 11.7 l/(s·km^2), while the same parameter averaged over the plateaus and lowlands of Estonia does not exceed 8.5-11.7 l/(s·km^2) [Resursy poverhnostnyh…1972]. Eastward of the Kunda River, conditions of groundwater recharge are not as favorable as in the Upland. This is a result of the lesser karstification of the carbonate bedrock and the widespread distribution of fens, where the infiltration is restricted.

Based of the total effect of topography and geological structures, three main groundwater flow systems are differentiated in the study area [Vallner L., 1980, Vallner L., 1997]. The local flow system enfolds chiefly the unconfined or locally confined shallow groundwater moving from its recharge area toward the nearest ditches, creeks, rivers, and discharging directly to Lake Peipsi or to the sea in the coastal areas. The intermediate flow system takes its rise from the Pandivere Upland, Jõhvi Height, and higher watersheds. It enfolds the lower portion of carbonate bedrock and the Ordovician-Cambrian aquifers. The completely confined branches of this system discharge in lower courses of rivers, on the North-Estonian Klint, in the Coastal Lowland and in Lake Peipsi. The regional flow system penetrates the Cambrian-Vendian aquifer system, where the groundwater flows northward and discharges in natural conditions in the Gulf of Finland. The regional flow system recharges by both the lateral flow coming from south and the transversal downward flow formed in the Pandivere Upland.

A detailed water budget of the study area has been completed (Table 26) on the basis of hydrogeological modeling [Vallner L., 2003, Vallner L., 1996a, Vallner L., 1996b]. This demonstrated that the simulated intensity of groundwater discharge to the surface water bodies corresponds to the average long-term intensity of the minimal river runoff observed at stream gauging stations during 30 days of the warm dry-weather-period every year.



1 – closed mine; outcrops: 2 – Lükati-Lontova basin-wide aquitard; 3 – Ordovician-Cambrian aquifer system; 4 - Ordovician carbonate aquifers; 5 – Uhaku local aquitard; 6 - outcrop line and index of a hydrogeological unit; 7 – water table contour of the Keila-Kukruse aquifer, m a.m.s.l in 2002; 8 - equipotential line of the Ordovician-Cambrian aquifer system, m a.m.s.l. in 2002; 9 – observation well and its number; 10 – line of the hydrogeological section A-B

Koostas: L.Savitski
Arvutigraafika: A.Saaremäe

Figure 44. Geological map of Northeast of Estonia [Savitski L., et al., 2001].

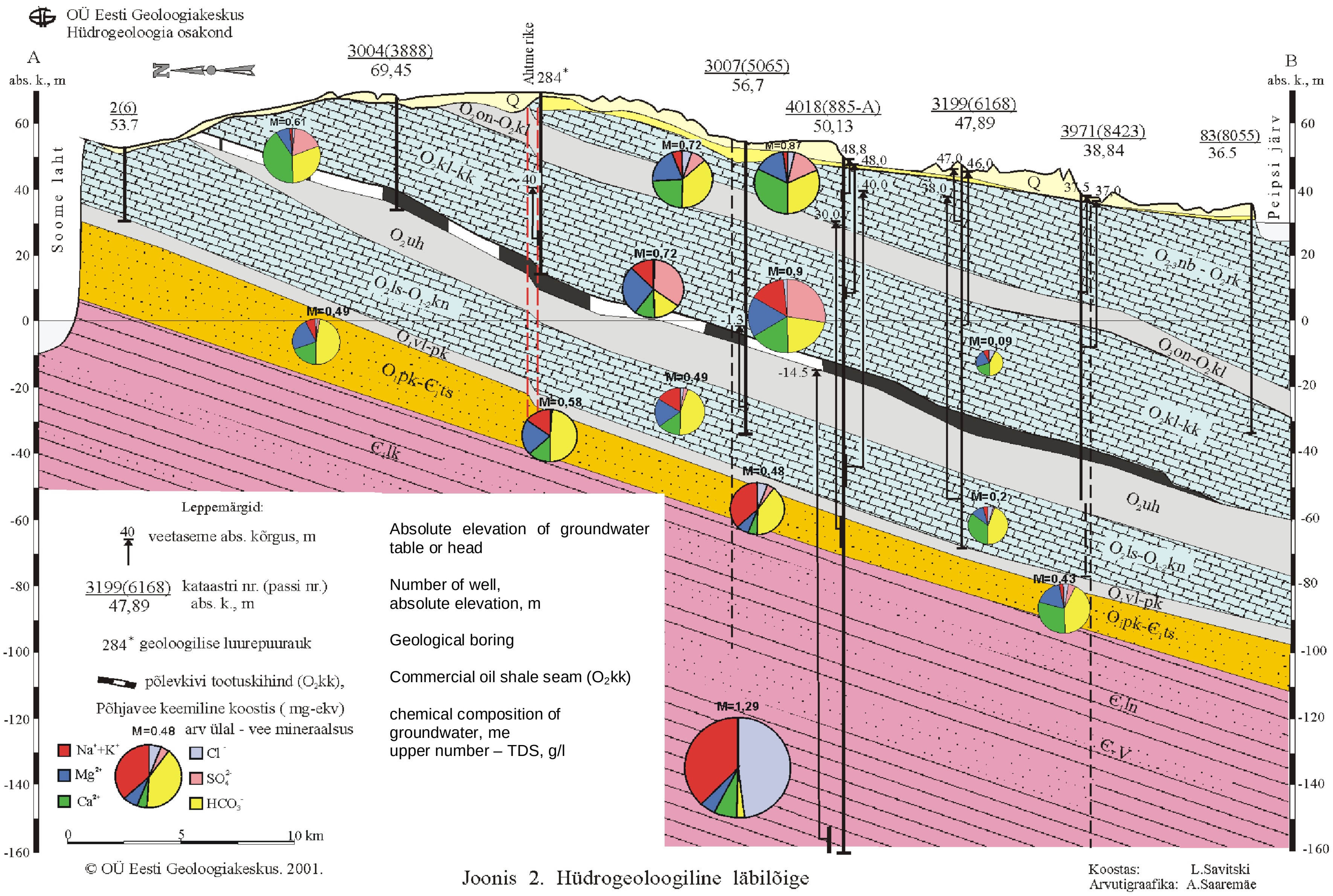


Figure 45. Geological section (see also Fig. 44 above) [Savitski L., et al., 2001].

Table 25. Correlation of geological structure, lithology and hydrogeological units of Ida – Viru county [Perens R., et al., 2001]

System	Subsystem	Regional stage	Index	Thickness, m	Units of hydrogeological stratigraphy
Quaternary (Q)			Q	0.5 – 77.0	Aquifer system of Quaternary deposits
Devonian (D)	Middle (D_2)	Narva	D_2nr	till 31.5	Sporadically waterbearing Narva aquifer
					Narva aquitard
Ordovician (O)	Upper (O_3)	Pirgu	O_3prg	36.3 – 47.3	Pirgu aquifer
		Vormsi	O_3vr	6.05 – 14.0	Vormsi weak aquitard
		Nabala	$O_{3\text{-}2}$nb	28.6 – 43.9	Nabala – Rakvere aquifer
	Middle (O_2)	Rakvere	O_2rk	8.0 – 13.3	
		Oandu	O_2on	0.70 – 4.95	Oandu medium aquitard
		Keila	O_2kl	7.0 – 15.5	Keila – Jõhvi aquifer
		Jõhvi	O_2ih	6.5 – 13.6	
		Idavere	O_2id	2.47 – 9.35	Jõhvi – Idavere weak aquitard
		Kukruse	O_2kk	6.30 – 19.15	Idavere – Kukruse aquifer
		Uhaku	O_2uh	9.75 – 20.5	Uhaku medium aquitard
		Lasnamäe	O_2ls	5.8 – 12.5	Lasnamäe – Kunda aquifer
		Aseri	O_2as	1.17 – 5.40	
		Kunda	O_2kn	5.15 – 9.0	
	Lower (O_1)	Volhovi	O_1vl	1.85 – 6.0	Lower – Ordovician aquitard
		Latorpi	O_1lt	0.05 – 2.6	
		Varangu	O_1vr		
		Pakerondi	O_1pk	0.15 – 18.7	
Cambrian (€)	Lower (€$_1$)	Pirita	€$_1$p	11.5 – 21.95	Ordovician – Cambrian aquifer system
		Lontova	€$_1$ln	31.8 – 45.2	Lükati-Lontova regional aquitard
Vendian (V)	Upper (V_2)	Kotlini	V_2kt	29.9 – 44.9	Voronka aquifer
				13.2 – 36.0	Kotlin regional aquitard
				11.7 – 45.9	
				26.6 – 46.5	Gdov aquifer
				0.4 – 19.6	
Meso-paleoproterozoic (PR)			$PR_{2\text{-}1}$	186+	

Table 26. Natural groundwater budget of the study area, m^3/day

Budget unit	Inflow				Outflow				
	From above	Lateral	From below	Total in	Up	Lateral	Down	Into surface water bodies	Total out
Quaternary cover & Silurian—Ordovician Aquifer system	1,313,000 (infiltration)	125,000	3,700	1,441,700	0	204,300	29,200	1,208,200	1,441,700
Ordovician—Cambrian aquifer system	26,200	1,000	0	27,200	4,200	3,200	5,000	14,800 (spring discharge on Klint)	27,200
Voronka aquifer	3,500	2,200	500	6,200	<100[1]	3,100 (into submarine area)	3,100	0	6,200
Gdov aquifer	3,000	4,100	0	7,100	600	6,500 (into submarine are)	0	0	7,100

[1]Flow rate <100 m^3/day has not been accounted at summation.

3.4.2. Impact of oil shale mining on water resources

As was mentioned, the extent of the main area of oil shale mining is approximately 60 km in a west-east direction from Kiviõli to the Narva River, and 30 km from Kohtla-Järve in the north to Sõrumäe in the south (Fig. 44) at places mainly covered by forests and bogs.

Opencast mining carried out encompasses an area of about 120 km^2, the area of underground mining encompasses about 280-290 km^2, chiefly south of Kohtla-Järve and Jõhvi in the central part of the Eesti oil shale deposit (Fig. 10, Fig. 44) [Reinsalu E., at al., 2002]. The floor of underground mines which coincides with the upper surface of the Uhaku aquitard, dips southwards at 3-4 m per 1 km. Its greatest depth reaches up to 70 m from the ground surface on the southern border of the Estonia mine at Sõrumäe.

3.4.2.1. Impact of draining and flooding of the mines

To keep the mines dry it is necessary to pump out all water intruding into goafs. It means that the Keila-Kukruse aquifer and the overlying layers must be sufficiently drained in the locality of a goaf. For that reason, a system of drainage slots, ditches, adits, and sumps, with a depth of 3 m or more, is cut into the goaf floor formed by the weak Uhaku aquitard. The gathering water is pumped out into the sedimentation pools and collecting channels dredged into the ground surface in the vicinity of mines and from there it flows, mostly itself, into the rivers network.

The total quantity of mine water depends mainly on the area of a goaf and its depth, permeability of layers drained, and precipitation. The annual amount of water pumped out from mines reached almost 300 millions m^3 in 1979, 1982, and 1988 but only 150-220 millions m^3 was pumped in 1976, 1980, and 1983 (Fig. 46). These changes were caused by rotating the dry and water-abundant periods. The mean annual mine water quantity was about 251 millions m^3 between 1976 and 1991. After 1991, the Ahtme, Kohtla, Sompa, and Tammiku mines were closed and the mining area decreased. The mean annual amount of mine water pumped fell to 198 million m^3 in the interval 1992-2004, too. The total quantity of mine water was about 203 millions m^3 in 2003, and the share of different mines ranged from 314 thousands m^3 to 68 millions m^3 (Table 27).

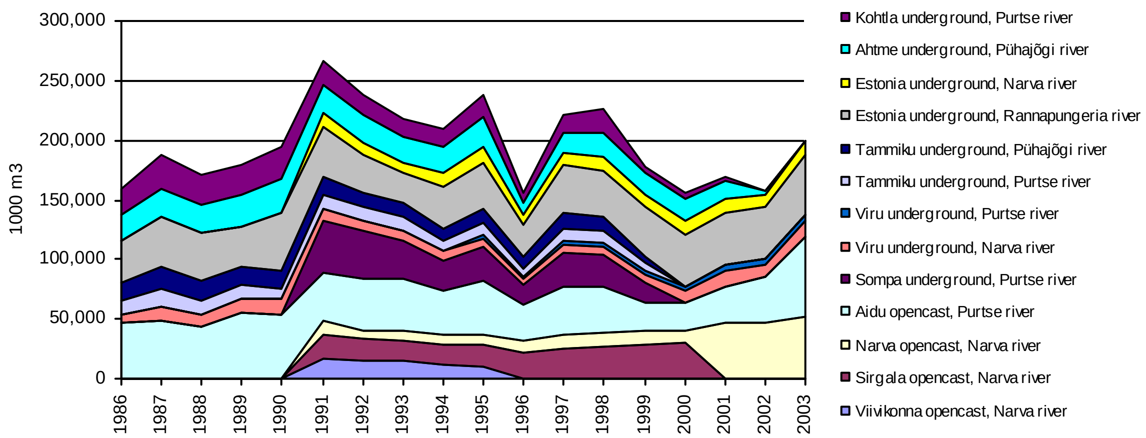


Figure 46. Mining waters by outflows [Estonian Environment Information Centre, annual reports of water management].

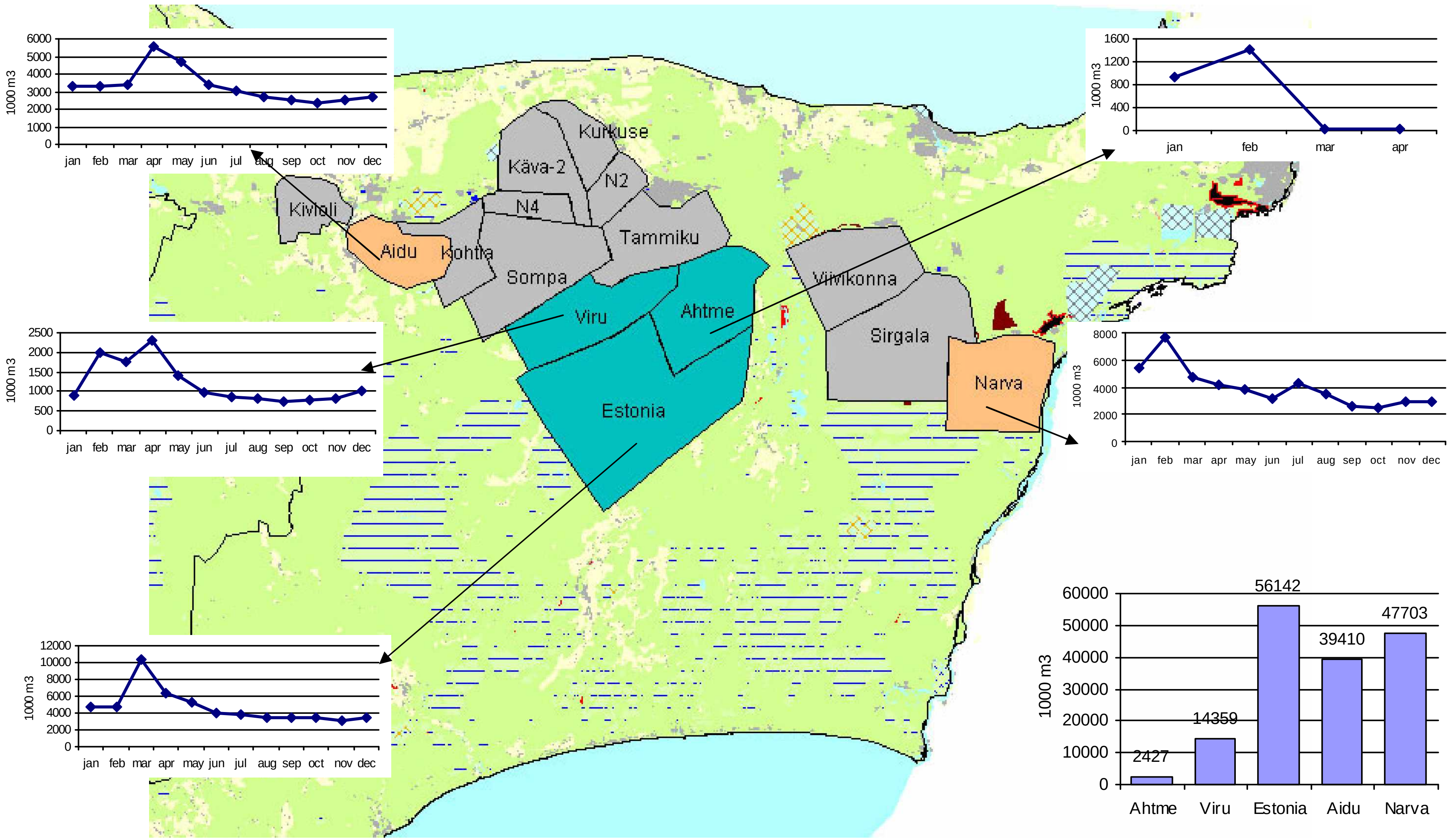


Figure 47. Water extraction by mining, monthly in 2002 [“AS Eesti Põlevkivi”, based on Basic map of Estonia (Estonian Land Board)].

The mine water consists of two components. One of them is the direct rain or thaw water influx into a goaf. Another component is the groundwater inflow. The distinguishing of the share of these mine water constituents is very important for the calculation of the fees that the oil shale industry enterprises must pay for consuming groundwater resources. At present, in the opinion of the Ministry of the Environment of Estonia, the share of groundwater should make up 30% of the total mine water [Lott R., 2005; Tammemäe O., 2005]. The ratio of the mine water components officially accepted is actually not justified.

The results of our calculations based on the groundwater budget analysis demonstrate that the share of the direct surface water influx in the total mine water ranges from 23% to 52% (Table 26). The groundwater inflow forms 48-77% of the mine water total, respectively. Thus, the share of groundwater in the total mine water must be ⅔ at least.

Table 27. The amount of mine water pumped out in 2003 [Perens R., at al., 2004]

Underground or opencast mine	Mean annual, m^3	Mean, m^3 day^{-1}	Share, %
Aidu	68,334,000	187,216	34
Estonia	63,001,000	172,605	31
Kiviõli	313,732	860	<0.1
Narva	52,196,000	143,003	26
Viru	19,146,000	52,455	9
Total	202,990,732	556,139	100

The water inflow into mines is very irregular seasonally (Fig. 47). The minimum inflow occurs in summer dry periods or in cold wintertime. On the contrary, the influxes into the goaf in spring or autumn can exceed the minimal inflow many times. This is characterized by the ratio $E = B_{max}/B_{min}$ where E is coefficient of irregularity of mine water inflow, B_{max} is the maximum seasonal inflow into the mine and B_{min} is the minimum seasonal inflow. The coefficient E depends on the depth of the mine. In a shallow mine where the overburden is thin and surface water can intrude into the goaf easily, the value of E can reach 30 [Savitski L., 1980]. At a mine depth of 60 m, the ratio E is usually not more than 2. The great seasonal irregularity of the mine water quantity hinders its possible consumption for technical purposes.

The coefficient of the water abundance W shows how many tonnes of water have been pumped out from a mine to excavate one tonne of oil shale. The W values are necessary for the economic assessment of the mining. At the mines and opencast pits considered the W values have changed from 5-6 to 80-90. However, the long-term mean value of the coefficient W is 11-13. In the late 1990s, the W value increased to 20 due to the general reduction in oil shale mining and the abundance of precipitation. In the last years, the coefficient W has decreased to the value of 15 [Viru-Peipsi Catchment…2004], partly in connection with trimming the mine water run-off channels. In places, the isolation of these channels was improved to prevent leakage of the mine water back into goafs. In comparison with world mining practice, the value of the water abundance coefficient is comparatively large. It means that dewatering the Estonian oil shale mines is expensive or even too expensive.

As a result of mine dewatering the groundwater head has often decreased along the mine perimeter to the level of the goaf roof. This is equal to a head drawdown from 10 to 70 m, dependending on the goaf depth. The depression of the water table extends up to 6-7 km from mines in the Keila-Kukruse aquifer [Perens R., et al., 2004]. The maximum area of this depression has reached about 600 km^2 in the 1990s. Because of the closure of a number of mines, the area of depression has reduced approximately by a half. The groundwater depression is the deepest in the mine overburden, depending on the state of the latter. In places the overburden has been heavily fissured, karstified, and caved because of undermining. Many unsealed geological and technical borings and ventilation shafts can penetrate the overburden and in places it does not contain any local aquitards. In such areas, the overburden has usually been completely drained and the groundwater table has dropped to the level of the mine roof. This situation prevails in places where the thickness of the overburden does not exceed 15-20 m. On the other hand, the local comparatively thin aquitards whose lateral extent is only some kilometers occur quite often in the main overburden. In this case the lenses of perched groundwater lie on these local aquitards.

The water table of the Nabala-Rakvere aquifer has dropped by 2-8 m predominantly under the influence of the dewatering of the Estonia mine [Domanova N., 1989; Savitski L., 2003]. The depression is observable at a distance of 1-2 km outside the mine borders [Viru-Peipsi Catchment…2004]. The drawdown in the confined Lasnamäe-Kunda aquifer reached 30-35 m in 1980 [Domanova N., 1989]. In Mäetaguse the pressure in this aquifer fell by 37 m between1978-2003 [Savitski L., 2003]. The head drawdown extends to a distance of 25 km from the mines [Viru-Peipsi Catchment…2004]. In spite of these drawdowns the head of the Lasnamäe-Kunda aquifer is by some meters higher than the head of the overlying Keila-Kukruse aquifer at the borders of operating mines.

Mine dewatering has evoked several negative phenomena. One of them is the decrease in the yield, or drying up of many shallow wells supplying rural households. Therefore, the adequate supply of water to these households has been a problem in the mining area. To overcome this problem more than 450 new wells have been bored by mining enterprises in rural settlements before 1996 [Rätsep A., 1999]. These wells have been sunk mostly into the Lasnamäe-Kunda aquifer, but unfortunately, this aquifer is at a growing risk of pollution. In the last decade, the deeper wells with a higher capacity have been predominantly bored into the Ordovician-Cambrian aquifer and pipelines from these wells to the consumers have been built. However, pollution is also spreading in the Ordovician-Cambrian aquifer and the pipelines often are in disrepair. Therefore, the water supply of rural households has still not been satisfactorily solved in the undermined area.

The dewatering of the Ahtme mine, and the Viivikonna and Sirgala opencast pits was one of reasons why the table of many unique lakes was lowered too much in the Kurtna Landscape Reserve. The water table of lakes was preserved only after construction of infiltration basins between the pits and the landscape reserve and the establishment of acceptable claim borders for mines.

The protected wetlands (Agusalu) are drained from the underside because of mine dewatering. For the time being the drawdown of the groundwater pressure induced by mine dewatering in the carbonate bedrock does not mostly exceed 2-3 m in their area. In places where the peat layers of boggy wetlands lie on varved clay, loam or clayey bedrock seams, the drainage effect of mine dewatering is comparatively weak and damage to wetland ecosystems is insignificant. However, because of mining activity some bog system have become dry and some of the wetland plants are disapearing.

Undermining of protected wetlands is in general inadmissible. Even the ventilation shafts damage the landscape and its water regime. Because of the strong irregularity of the conductivity properties of the carbonate bedrock, it is not possible to predict exactly the degree of the wetland drainage under the influence of mine dewatering, claim borders must be established between the protected wetlands and mines guarantying the stability of wetland water systems. It is completely wrong to predict the water situation in a wetland endangered by mine dewatering based on an apparent hydrogeological analogy. Special borings and monitoring of the water table are necessary for elaborating the founded (justified) decisions.

In places arable lands and settlement territories suffering from excessive moisture in predevelopment conditions have drained because of mine dewatering. This is a favourable phenomenon until the mine dewatering impact becomes too great [Soovik E., 2005].

The degree of drainage of the overburden depends on its hydrogeological properties, number of penetrating borings, and the mining method used. The behaviour of the mine overburden is conditioned by the mining method used [Liblik V., et al., 2005; Reinsalu E., et al., 2003; Reinsalu E., et al., 2002; Undusk V., 1998]. For the underground mining of oil shale room mining (1922-1962), longwall mining (1946-2001), and room-and-pillar mining have been carried out (1960 until present).

In room and longwall mining, oil shale was excavated but the host rock was left in the goaf as a gangue. The roof was let down on the gangue, filling the goaf. As a result of dropping the overburden, a subsidence of the ground surface occurred on undermined areas. The maximum extent of these subsidences has been 0.6-1.7 m [Toomik A., 1999; Reinsalu E., et al., 2002]. The deformations of the overburden and ground surface are rectangular. The rate of subsidence gradually decreases in the direction of mine pillars left in the goaf. Subsidence has mostly ceased one year after the mine roof was let down.

The mining field is divided into rectangular panels in room-and-pillars mining. The panels are subdivided into mining blocks of size 300-350 m x 600-800 m [Toomik A., et al., 2001]. In the mining, about ¾ of oil shale is excavated from the minefield, but the remaining portion is left in the goaf as a set of quadratic pillars, which support the overburden. The territory mined out by this method will not deform during some years after termination of the underground works, but it will be unstable for a very long time.

Dewatering of exhausted underground Kiviõli, Kohtla, Käva, Sompa, Tammiku, and Ahtme mines has ceased between 1989 and 2002. The result was that the groundwater table began to rise and the mines mentioned, with a total area of 220 km^2, were flooded in the course of a couple of years. The total volume of goafs filled by water was about $1.3 \cdot 10^8$ m^3 in 2003 [Savitski L., 2003].

Flooding of mines evokes new problems. A number of places, including some suburbs of Kohtla-Järve, Jõhvi and Ahtme, and forestlands, having comparatively low topography, were drained due to mine dewatering during several decades. These areas suffered from excessive moisture or were even flooded after the cessation of mine drainage. In this connection, it is necessary to build additional expensive drainage systems in settlements and forestlands become boggy [Rull E., et al., 2005]. To prevent the disadvantageous effects of mine flooding, the water table must artificially be kept on a suitable elevation in the abandoned mines. This is done using special ditches allowing the outflow of excessive water from flooded mines into the river network. However, some of the water from the flooded Kohtla and Ahtme mines flows into the operating Viru and Estonia mines. Therefore, the dewatering costs of Viru and Estonia mines have risen. Special attention must be paid to the abandoned Kiviõli and Ahtme mines. There the water table may not be allowed to exceed the absolute elevation of 41 m to avoid the spreading of pollution outside the mine borders.

Before mining, the chemical type of groundwater[9] was predominantly HCO_3-Ca-Mg or HCO_3-Mg-Ca with total dissolved solids (TDS) between 0.3-0.6 mg/l in the carbonate bedrock [Karise V., 1997; Perens R., et al., 1999; Savitski L., 2003]. The content of the sulphate usually varied in ranges 60-100 mg/l in the water of the Keila-Kukruse aquifer. The total hardness of this water was mostly 6-8 me/l.

Due to dewatering of mines, the thickness of the aeration zone increased from 1-3 m to 20-40 m or even more. It favoured the intrusion of free air oxygen into the carbonate bedrock containing pyrite (FeS_2). Because of the contact between oxygen and pyrite an intensive

[9]The chemical type of water expresses the content of macro components whose share in the total equivalent weight of cations and anions is more than 20%, the ions are listed in descending order of content value.

oxidation of pyrite took place accordingly to the following reaction formula [Triegel E. K., et al., 1993; Williamson M. A., et al., 1994]:

$$FeS_2 + 7O_2 + 2H_2O \rightarrow Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+.$$

It has caused a significant enrichment of mine water by sulphate. As a result, in many cases, the content of sulphate has reached 300-600 mg/l in mine water. The hardness of mine water has increased up to 10-20 me/l. The mine water is often polluted by oils leaking from various mining machines and contains a lot of suspended clayey matter.

Large-scale pollution of aquifers and surface water has been caused by underground fires. Most of those are due to technological shortcomings in oil shale mining. Depending on the intensity of the underground fire and the abundance of oxygen, liquid products of cracking (and among these phenols) escape into the environment. With the water that has been used to put out the fires, polluting substances are carried into aquifers and streams. Underground fires have occurred quite often in the oil shale region, some of them lasting several years. For instance, one of the largest mine fires occurred in the Estonia mine in 1988 [Parahhonski E., 1989]. The fire spread quickly and underground distillation of oil shale began. Within a week after the fire had broken out, the amount of phenol in mine water was 500 times higher then the permissible level. The polluted water flowed into Rannapungerja River and Lake Peipsi.

In 1951 efforts were made to carry out underground cracking of oil shale with the aim of producing combustible gas in the vicinity of Kiviõli. These experiments failed, but the shallow groundwater heavily polluted by phenols was discharged into the Purtse River. To prevent the spreading of this pollution, the underground cracking area was more or less isolated by a concrete partition and the height of the water table is kept under the control in the Kiviõli abandoned mine.

After flooding of mines, the content of sulphate, TDS and hardness increase in their water up to twofold in the course of some years (Table 28) [Savitski L., 2003]. Later an opposing process takes place – the values of these characteristics begins to decrease.

Table 28. Water characteristics of the Kiviõli mine

Year	Hardness, me/l	Content of sulphate, mg/l	TDS, mg/l
1988 (before flooding)	21	732	1,610
1989 (after flooding)	29.8	1,241	2,250
1993	11.8	295	826
2000	8,7	231	780

The content of micro components has been determined in the water samples taken from the Tammiku, Sompa, and Kukruse mines, and from Mine No 2 [Pöyry J., 2000]. Excessive amounts of some components were detected which exceeded the permissible limits (Ni: 14,2 µg, Tammiku mine; Co: 7.6 µg, Sompa mine; Ba: 97.2 µg) [Pinnases ja põhjavees…2004].

A dangerous concentration of benso(a)pyrene, reaching 0.12 µg in the water of Mine No 2, 0.14 µg in the Tammiku mine, 0.17 µg in the Sompa mine and 0.43 µg in a sedimentation bond of Mine No 2, was determined in 2000 [Pöyry J., 2000]. The maximum permitted content of highly toxic benso(a)pyrene is only 0,01 µg for drinking water [Pinnases ja põhjavees…2004]. Later an inadmissible content of benso(a)pyrene was not detected by the Estonian Environmental Research Centre in water of oil shale mines [Savitski L., 2003]. Despite the results of the latter investigation, the problem of benso(a)pyrene content in waters of the oil shale basin needs serious attention.

Accordingly to a personal communication of I. Veldre it was established that polycyclic aromatic hydrocarbons in the vicinity of oil shale industry concentrate in the bottom sediments of surface water bodies and are incorporated in various food chains where they accumulate in aquatiq plants and fish [Vallner L., et al., 1993]. They may cause tumours in fish. These carcinogenic polycyclic aromatic hydrocarbons in fish can affect humans consuming the fish.

3.4.2.2. Impact of mining on the natural surface water bodies

Natural water quality in the surface water results from the influences of the following three factors: the chemistry/mineralogy of the deposit the water contacts, water contact time and flow path. The data available on the state of lake water sulphate content before World War II is quite limited. However, the earliest published data, characterizing the water sulphate content of Kurtna lakes at the end of the 1930s, can be found in literature [Riikoja H., 1940]. In 1937, the sulphate content was in the range of 1-7 mg/l in the lakes, and presumably also in the groundwater. Variations in the sulphate content seem to have been caused mainly by natural factors in the lakes or surrounding deposits. At that time the land use was rather modest and the area was sparsely populated.

In the Vasavere buried valley, down to the depth of 70 m the groundwater was of HCO_3–Ca–Mg type with a mineralization of 0.5 g/l [Riikoja H., 1940]. Modelling based on the oldest available data suggested low sulphate content in both the lakes and shallow groundwater in August 1937.

Several studies [Ilomets M., 1987; Ilomets M., 1989; Punning J.-M., 1994; Domanova N., et al., 1995; Domanova N., 1996; Domanova N., et al., 1997; Liblik V., et al., 1999; Savitskaja L., 1999; Erg K., 2000; Punning J.-M., 2000; Savitski L., 2000, Erg K., 2005] have been completed in the oil shale deposit, especially in the Vasavere buried valley with regard to the lake water quality. The rise in the sulphate content of lake water is evidently due to human impact. In recent years the content of sulphate has increased both in the closed lakes and in those (L. Nõmmejärv, Särgjärv, Ahvenjärv and Konsu), influenced by mining waters directly (discharge) in the southern part of the Vasavere valley, or indirectly (infiltration lakes Kastjärv, Pannjärv and Rääkjärv) by mining dewatering system waters, having sulphate values in the range 160–259 mg/l.

If, for example, in 1937 the sulphate content in the lakes Nõmmjärv and Konsu was 5.8 and 1.0 mg/l, then in 2000 it was 259 and 184 mg/l, respectively; in the shallow groundwater the content of sulphate increased more than 50 times during 1937–2000 [Erg K., 2005].

3.4.2.3. Post-technological impact of mining on regional water resources

Closed underground mines may pose or induce risks for the environment. Some of these risks are linked to the shut down of the mine water pumping operations leading to a water level rise. These concern:

1. pollution of surface and/or groundwater by sulphates and others chemical elements;
2. flooding of zones that have subsided below the water table level during the mining;
3. additional surface movements as a result of the collapse of shallow mine workings.

After the closing of a mine these risks may exist during a short, long and very long period of time depending on the quantity and flow of water involved and the volume of the mine workings concerned.

In the closed oil shale mines, pumping from the working mine is terminated and mine voids are allowed to re-saturate. Flooding of closed mines will generally continue until groundwater achieves a new equilibrium. Before reaching the steady-state, the sulphate content sharply increases; some years after flooding it decreases. Oil shale mining forms large areas of horizontal zones of empty openings and voids, which are defined, after flooding of the mine, as mine water reservoirs in closed mines.

The hydrogeology of underground operational (Viru and Estonia mines) and closed mines was studied by Savitski and Savva [Savitski L., et al., 2001; Savitski L., 2003] and most recently by the researchers of the Department of Mining of TUT under the supervision of Reinsalu [Reinsalu E., et al., 2004].

In the mines that are already flooded or will become flooded, groundwater with a sulphate content of 300-600 mg/l; mineral content of 0.6-1.1 g/l and hardness of 8-15 mg-eq/l forms. The quality of the water contained in flooded mines will probably improve with time but the use of such water for drinking water supply is still impossible due to the overly big risks [Viru-Peipsi Catchment…, 2004].

The water also endangers the water quality of the existing wells and aggravates the problems of the water supply to the population of exhausted areas. After the closure of the Ahtme mine, water quality will be a danger also for the Vasavere ancient valley and Vasavere water intake.

When the underground mines are closed, the pumping of water stops and the old shafts and tunnels fill up with water. The hydraulic conductivity is mainly determined by the degree of fracturing, by local karst and by human impact. As a rule, the hydraulic conductivity of host rock is at its highest near the surface, and reduces gradually downwards. This causes the highest influx of shallow groundwater into shallow (40 m) underground mines.

In underground oil shale mines, there may be a number of disconnected pools at the early stage of flooding. Before flooding, water sub-pools may exist at various locations and elevations within the mine. The abundance of sub-pools is the greatest at the back of the mine where recharge and leakage collect. These sub-pools tend to coalesce and form a main pool, which will rise from the back of the mine in an up-dip direction. As flooding progresses, the sub-pools join into a single main pool with a large volume (Table 29). However, the main pool may stabilize at a lower elevation if water-control measures are implemented or the mine spills into an adjacent mine.

Table 29. Approximate water volume in closed underground oil shale mines

Underground mine	Work started	Closed (pumping stopped)	Water table in 2003[1)]		Mined out area[2)], km^2	Water volume (approximately), 10^6 m^3	
			Obs.well	m, a.s.l.		in 2003[3)]	in 2004[4)]
Kukruse	1916	1967	8214A	52	13	3.6	5
Käva	1924	1973	2	51.5	18	9	10
Kohtla	1937	28.06.2001	W-15	41	17	10	13
Ahtme	1948	1.04.2002	16122	25	35	60	63
Sompa	1949	2.12.2000	487	43	27	23	23
Mine 2	1949	1974	3a	51.41	13	7	7
Tammiku	1951	28.12.1999	714 8208 1099	47.95 50.04 47.92	40	~40	42
Mine 4	1953	1975	302 I b	41.18 40.26	13	1.4	2.0

[1)]Savitski L., Boldõreva N., 2005; [2)]Reinsalu E., et al., 2002;
[3)]Savitski L., Boldõreva N., 2005; [4)]Erg K., 2005;

See also Fig.2 and Fig.3 in Appendix VII

The flooding situation is a transient scenario, while the flooded case is a steady state one. In transient groundwater flow systems, hydraulic head is continuously changing with time, with minor seasonal or annual fluctuations. In 2003, the volume of water in the pools of the closed underground mines was about 160 million m^3 [Domanova N., 1999; Savitski L., et al., 2005]; in 2004 it amounted to 170 million m^3 [Erg K., 2005]. The elevation of the water table in 1990 was about 42–53 m above sea level in Käva and Kukruse mines, Mine No. 2 and Mine No. 4.

In 2004 it was hypothesized that much larger variation in the water level could occur as a result of technogenic karstification processes [Reinsalu E., et al., 2004]. In some cases, water levels in two or more adjacent mines will fluctuate in conformity with seasonal or human-induced stresses. Hydrologic investigations indicate that the elevation of the water table has fluctuated over time, especially in Mine No. 2. The maximum elevation was about 51 m above sea level, but seasonally it fluctuated between 50-56 m above sea level, primarily as a result of variation in climate and increased precipitation. If the inflow rate is all the time greater than the outflow rate, the water storage and hydraulic head in the saturated portion of the mine will increase. If outflows are greater than inflows, then the hydraulic head will decline. During the rainy August of 2003, the water table rose 4 m in Sompa underground mine, 2 m in Kohtla, 2.1 m in Kukruse, 1.8 m in Mine No. 4 and 0.5 m in Ahtme mine.

Estonia and Viru underground mines advance from shallow to deep cover and lie below regional drainage elevations. As mining progresses, groundwater can infiltrate into the mine. Therefore, the mine is progressively dewatered to allow mining to continue. As deeper mines are commonly separated from shallower up dip mines by thick barriers of unmined oil shale, the shallow closed mines may be flooded while deeper mining continues. One of several regulatory issues regarding the closure of such mines is long-term discharge of water after the mines have fully flooded. Following mine closure, pumping from the active mine is terminated and mine voids are allowed to re-saturate. Flooding of closed mines will generally continue until groundwater achieves a new equilibrium, either by surface discharge of mine water or by controlled pumping and treatment. Eight of the underground mines located in the central part of the oil shale deposit were flooded in 2004 by groundwater, which caused flooding in the northern part of Jõhvi Town.

The area of flooded mines is currently about 220 km^2 of the most densely populated areas in the Ida-Viru County and the estimated amount of water in the caves is 130-170x10^6 m^3 [Savitski L., 2003], as indicated.

3.4.2.4. Water pollution in closed mines

The expected largest post-technological impact of oil shale mining on the state of the groundwater bodies is associated with the formation of a huge polluted underground water reservoir. Detailed patterns of the distribution of pollutants in the ground water bodies are in need of careful further investigation. Due to the decomposition of the rock destabilized by thousands of explosions in the flooded mines, regional pollution of deeper groundwater bodies with sulphates, phenols, carbonates and even benzo(a)pyrene is a real threat in the future. Problems associated with the pollution are under-estimated until now. Regional pollution of the groundwater bodies would in fact make it necessary to construct an alternative water supply system for the mining area with more than 150 000 inhabitants.

The biggest and best-studied groundwater pollution problem associated with underground mining is the intensive **pyrite oxidation**, caused by the water level drop and the formation of a larger aeration zone. After mine closure the water level rises and pyrite oxidation decreases. The most noticeable change will take place in the sulphate content.

In the time before mining commenced, the groundwater quality was mainly affected by precipitation. During the mining period the sulphate content increased by a factor of up to 50 compared to natural conditions (2-10 mg/l). In the post-mining period the mines fill with water; the content of sulphates increases sharply – 3-4 times (1,200 mg/l) during two years, and then, after four years, decreases to 150–200 mg/l, remaining still 10 times higher than its natural background level [Erg K., 2005].

This is naturally accompanied by intensive removal of the sulphates containing in Ordovician carbonate rocks. Significant enrichment of water with the sulphates takes place in the carbonate rocks in the aeration zone. There is increasing evidence that some of the water infiltrating through the soil surface may move rapidly through the aeration zone along preferred flow paths such as macrospores and fractures. In many cases, the water has low pH and contains elevated levels of sulphate ions. In recent years, in the area of oil shale mines, the chemical composition of groundwater has been stable. The content of SO_4 in groundwater was 2 times higher in spring than during the remaining seasons of the year. It can be caused by dissolution of pyrites in oxygen-abundant water in spring [Erg K., 2005].

Lateral distribution of sulphate in the water of closed mines - reasons may be in mine filling, which depends on precipitation and results in water level rising. This water washes the already oxidising pyrite products out of the limestone, and the sulphate content in groundwater will increase. The sulphate may disimute in a literal direction many times more rapidly than in a transversal direction. This may be explained with the permeability of groundwater aquifer or aquifer system.

Transversal distribution of water sulphate from closed mines' water pool to the Lasnamäe–Kunda aquifer - after the closing of oil shale mines, the sulphate content in the Lasnamäe–Kunda aquifer is higher than the natural level of the same aquifer. The effects of mine filling and other closure measures can be evaluated on the basis of infiltration of Keila-Kukruse or mine pool water to the Lasnamäe-Kunda aquifer. Based on the chemical data of Lasnamäe–Kunda aquifer from the period before mining and after closure, the amount of mine water in the above- mentioned aquifer can be estimated. Judging by the sulphate content, the amount of water in the Lasnamäe–Kunda aquifer is relatively large in water pools of different underground oil shale mines (Table 30) [Erg K., 2005].

Table 30. The share of underground oil shale mine pool water volume in the Lasnamäe–Kunda aquifer according to the sulphate content [Erg K., 2005]

Observation well	Underground mine	Mixed water sulphate content, mg/l	Sulphate content		Mine pool water capacity in the Lasnamäe-Kunda aquifer, %
			Lasnamäe-Kunda aquifer, mg/l	Keila-aquifer, mg/l	
15955	Sompa	446	126	1196	30
19629	Tammiku	597	229	780	67
15485	Mine No. 4	395	406	300	10
13513	Mine No. 2	369	250.6	500	47
13583	Käva	323	171.6	1289	14
14388	Kukruse	159	140	200	32

See also Fig. 2 and Fig. 3 in Appendix VII.

In 2003, in the earliest closed underground mines (Kukruse, Mine No. 2) the sulphate content in the Lasnamäe–Kunda aquifer was high. In the western part of Tammiku mine, the Lasnamäe–Kunda aquifer was very high in sulphate. This is promoted by karst and technogenic faults. The Ahtme mine water pool exerted a weak (27%) influence on the Lasnamäe-Kunda aquifer. In the southern part of Kohtla mine and in the northern part of Sompa mine the sulphate content in the Lasnamäe-Kunda aquifer was between 200-320 mg/l. The amount of pool water from Mine No. 4 and also Käva mine in the Lasnamäe-Kunda aquifer was lower, 10 and 14%, respectively, than in the other mines. In this region, a relatively impermeable aquitard may be located between the mine pool area and the Lasnamäe-Kunda aquifer. The distribution of sulphate in the Lasnamäe-Kunda aquifer may be due to the circumstance that the permeability of carbonated rock in a lateral direction can be up to 100 times higher than in a transverse direction. The same effect is observed in the Keila-Kukruse aquifer [Erg K., 2005].

3.4.3. Overexploitation of aquifers and groundwater proved reserves

Overexploitation of aquifers is considered to be one of the main problems of modern hydrogeology, which will cause inadmissible deterioration of groundwater by different unfavourable intrusions [Custodio E., 2002]. At present the understanding that the groundwater consumption must not exceed its long-term natural recharge prevails [Scanlon B., et al., 2002; Vries De M., et al., 2002]. However, some researchers suggest that a number of other factors limit an acceptable abstraction rate, too [Barnett S.-R., 2002; Bredehoeft J., 2005, 2002; Devlin J.-F., et al., 2005; Sophocleous M., 2002, 2005]. A lot of methods and variable approaches have been elaborated for the determination of an optimum groundwater withdraw, which is also called the sustainable yield [Alley W.-M., et al., 2004; Brutland G.-H., 1997; Freeze R.-A., et al., 1997; Gingerich S.-B., et al., 2005; Hiscock K.-M., et al., 2002; Kalf FRP., et al., 2005; Kendy E., 2003].

Unfortunately, until recent times, civil servants have not adequately understood the hazards resulting from overexploitation of groundwater in Estonia. Here the water management has predominantly been based upon the conceptions of the groundwater proved reserve, enforced in the Soviet era [Iodkazis V., 1980; Vallner L., et al., 1998; Vallner & Savitskaja 1997]. The groundwater proved reserve (‘põhjavee tarbevaru’ in Estonian) was defined as an amount of groundwater that could be withdrawn in a rational mode accordingly to a given pumping schedule without worsening the ecological situation [Keskkonna-alaste…1998]. It was also required that the quality of the pumped water must remain in the acceptable ranges during the abstraction period foreseen for the intake. The real abstraction rate of an intake must not exceed its calculated proved reserve. The Groundwater Commission at the Ministry of Environment must certify the proved reserve estimated.

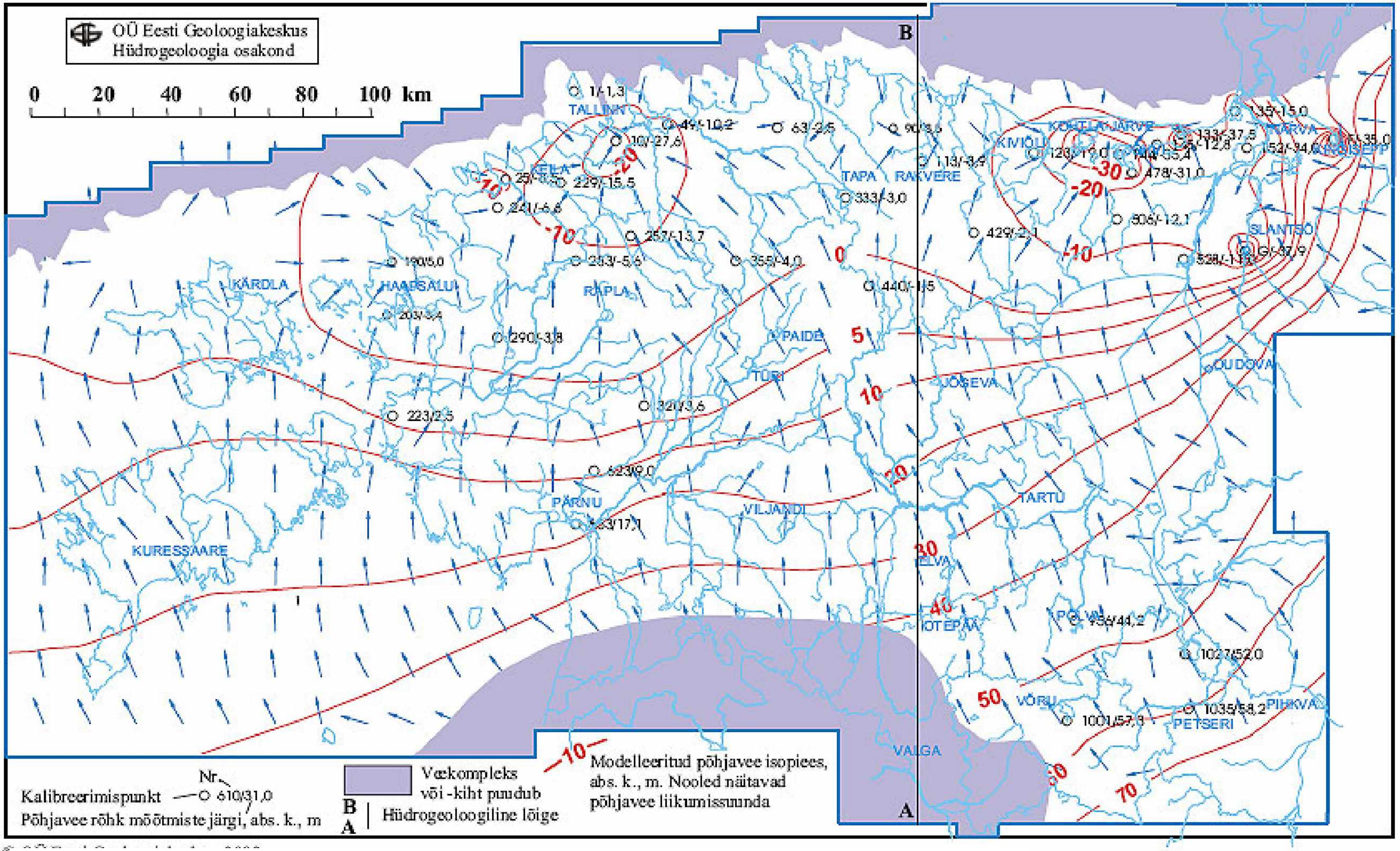
Specification of the groundwater proved reserve did not explain what to understand by ‘the worsening of the ecological situation’. No restrictions were established on the lowering of groundwater table or pressure in aquifers due to the pumping. As a consequence of these uncertainties, the main attention in the calculation of the groundwater proved reserve was paid chiefly to the warranted pumping rate expected by water consumers. The possible undesired effects of a too intensive abstraction on surface waters or other aquifers were not analyzed enough, or they were ignored altogether.

The Water Act of Estonia [Veeseadus, 1994] required calculation of the groundwater proved reserve for every intake where the pumping rate exceeded 500 m^3/day. Therefore, despite the shortcomings described above, the groundwater proved reserves have been calculated for all main groundwater intakes of the study area until 2012-2035 (Table 31) [Perens R., et al., 2004; Savitski L., et al., 2005]. Until 2012 the total of proved reserves of Cambrian-Vendian aquifer system is 77,655 m^3/day. After that, the proved reserves of this aquifer system will be decreased in the central part of the study area and their total will average 56,550 m^3/day.

Groundwater proved reserves calculated and certified officially in fact legalized the overexploitation of aquifers in the study area. It has significantly worsened the ecological state of the aquatic environment. First of all, it concerns the Cambrian-Vendian aquifer system and the Quaternary aquifer of the Vasavere buried valley.

Between 1954 and 1991 groundwater abstraction from the Cambrian-Vendian aquifer system grew in the range 5,000-63,000 m^3/day [Põhjavee seisund…1999]. The result was that a head depression emerged in this aquifer system that encompassed the whole of northeast Estonia (Fig. 48, Fig. 49). If, in predevelopment conditions, the head of the Voronka aquifer was about 10 m a.m.s.l in Jõhvi [Vallner L., 2002], then it had fallen by 63 m, up to 53 m b.m.s.l, in 1991. The head was lowered below the sea level in the whole area of Lääne-Viru and Ida-Viru Counties. In this situation, the groundwater being moved northward under predevelopment conditions in the submarine portion of the Cambrian-Vendian aquifer system, started to soak backwards – from seaside toward the coast. It concurred with an intrusion of saline seawater into this aquifer system. Saline water surely will encroach into the coastal groundwater intakes if the groundwater head remains below the sea level in the terrestrial portion of the Cambrian-Vendian aquifer system over a long time. Deep head depression has likely also been caused by an upconing of brines from the crystalline basement or the lowest Vendian strata (this has already happened in Tallinn [Karro E., et al., 2004]).

Since 1992 the pumping load on the Cambrian-Vendian aquifer system has decreased because of more economical water consumption in the study area. However, the total pumping rate from the aquifer system was about 19,000 m^3/day and the head of the Voronka aquifer 22-24 m b.m.s.l in Jõhvi in 2003. The head of the Voronka aquifer was 10-20 m b.m.s.l. along the seashore between Purtse and Sillamäe. Consequently, the saline water intrusion and movement toward the coast had decelerated in comparison with 1991, but it was continuing. Regardless of the reduction of proved reserves beginning from 2013, the groundwater head in the Voronka aquifer will be 12-20 m b.m.s.l, and in the Gdov aquifer, 8-11 m b.m.s.l along the shore between Purtse and Sillamäe in 2035 (Fig. 50) [Savitski L., et al., 2005]. The head of the Voronka aquifer will lower to 40 m b.m.s.l in Sillamäe in 2035. The influx from the submarine portion of the Cambrian-Vendian aquifer system into the terrestrial part of the latter will reach 7,300 m^3/day. Obviously, it is accompanied by the intrusion of the same amount of saline seawater into this aquifer system.



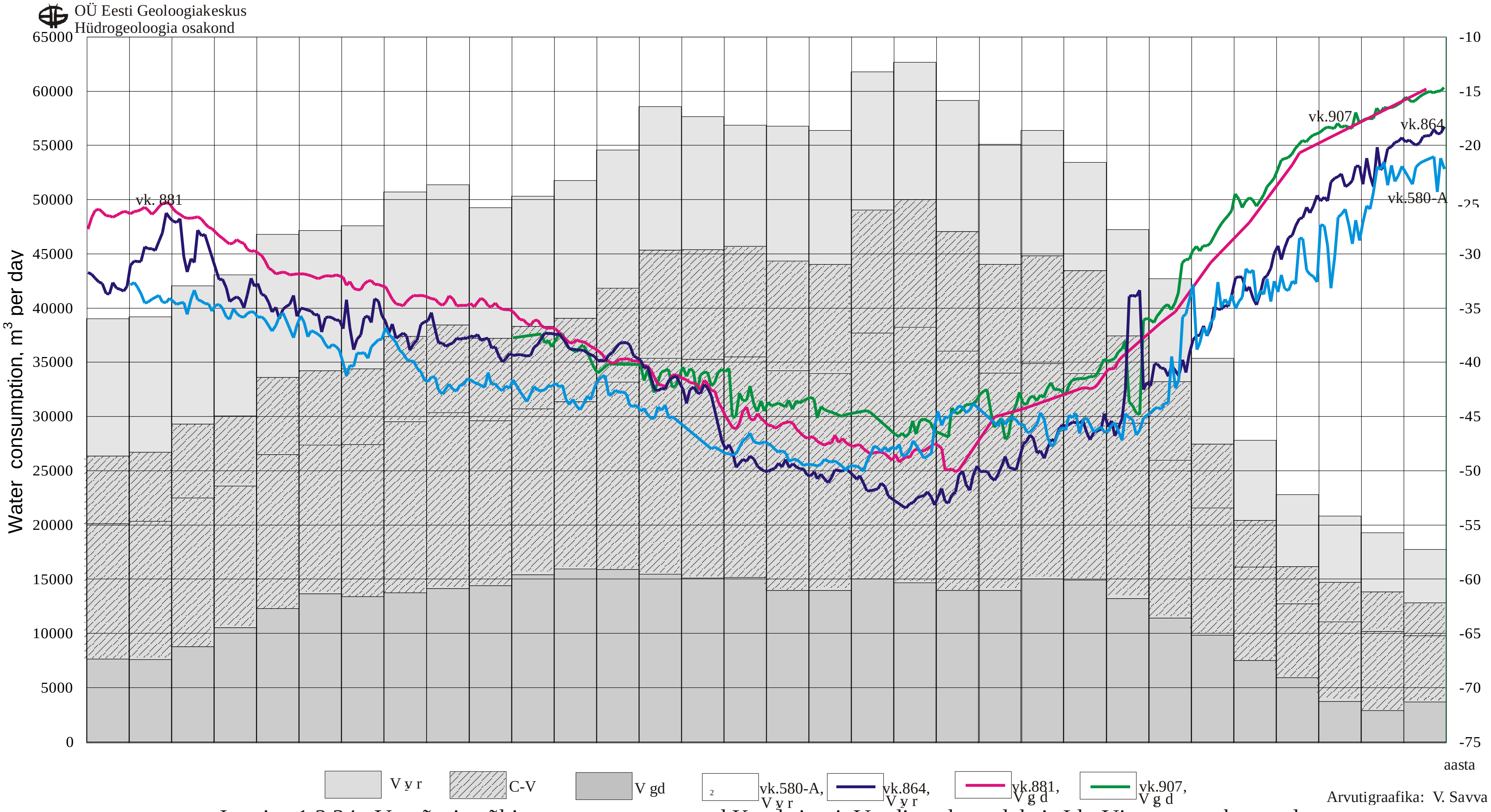
Calibration well
Groundwater head observed

Aquifer system or aquifer does not exist
Hydrogeological section

Equipotential line simulated, absolute elevation, m
Arrows show direction of the groundwater movement

Joonis 17. Põhjavee rõhk ja liikumissuund Kambriumi-Vendi veekompleksis ning Voronka põhjaveekihis 1976. aastal. *Autor: L. Vallner*

Figure 48. Directions of the groundwater movement (arrows) and head contours (absolute elevation) in the Cambrian-Vendian aquifer system and Voronka aquifer in 1976 [Vallner L., 2002].



Joonis 1.2.34. Veevõtt ja põhjaveetaseme muutused Kambriumi–Vendi veekompleksis Ida-Virumaa veehaaretel.

Figure 49. Groundwater abstraction and head changes in the Ida-Viru County [Perens R., et al., 2005].

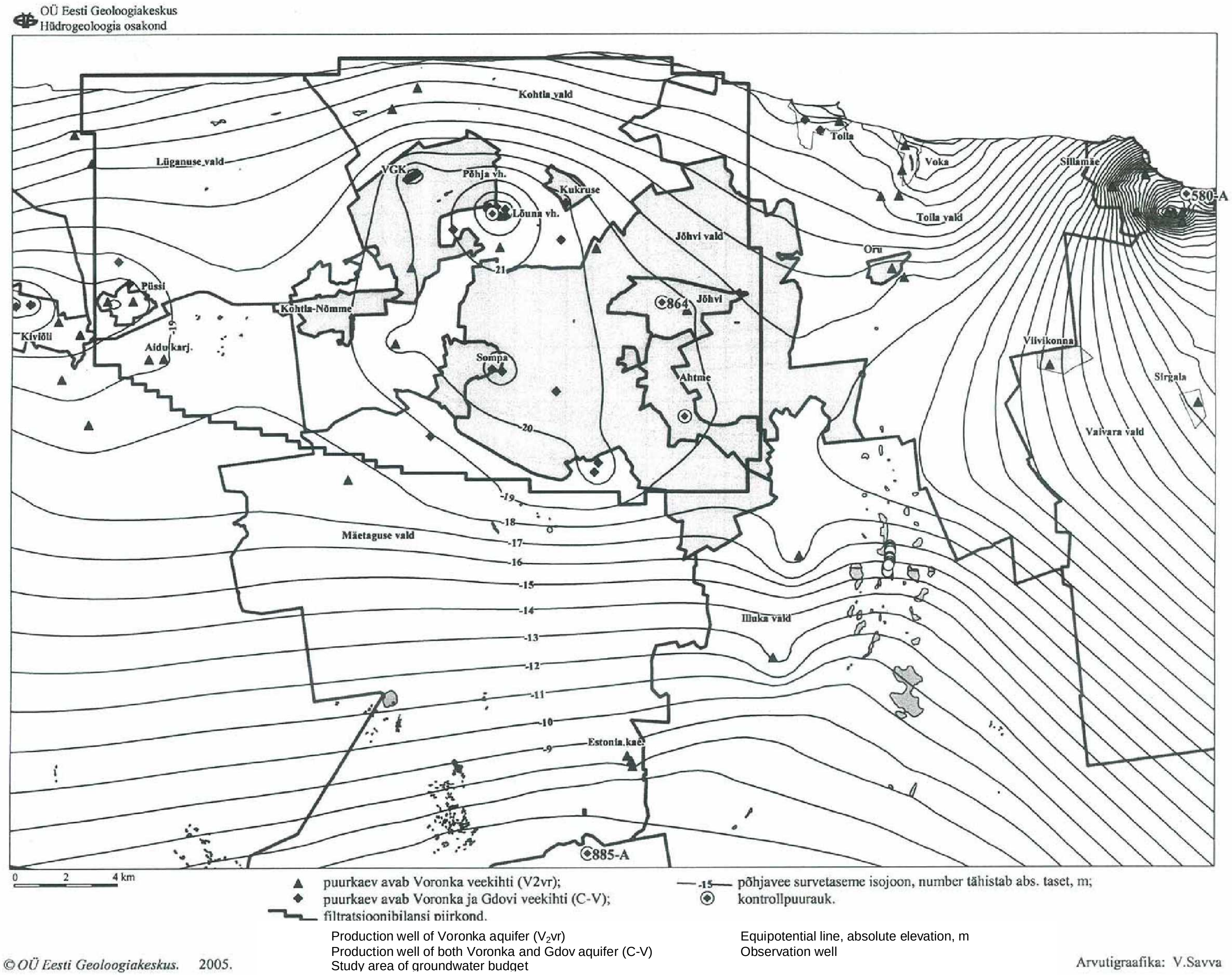


Figure 50. Head contours (absolute elevation) of the Voronka aquifer in 2035 [Savitski L., et al., 2005]

According to groundwater transport simulations, the saline water will reach Narva-Jõesuu in the Voronka aquifer in 2020 [Savitski L., Vallner L., 1999; Vallner L., 1996a, Vallner L., 1996b] if the groundwater abstraction from the Cambrian-Vendian aquifer system corresponds to proved reserves certified in 2000 [Savitski L., Savva V., 2000a]. Using the same method, V. Savva found out that the front of saline water would flow to Sillamäe in 2020, too [Savitski L., Savva V., 2000b].

To intensify the water supply of Kohtla-Järve urban area, a groundwater intake with a planned rate of proved reserve of 25,000 m^3/day, using the Quaternary aquifer of the Vasavere buried valley, was put into operation in 1971. The intake was within the Kurtna Landscape Reserve which features wooded hillocks and ridges with a lot of picturesque lakes, many of them with unique hydrobiological biocenoses. Unfortunately, already at the pumping rate of 10,000 m^3/day the water table of several lakes fell below the acceptable minimum level and the unique biocenoses were irreversible damaged [Mäemets A., 1987]. The content of sulphate grew from 1-6 mg/l to 260 mg/l in the water of some lakes because of polluted intrusions induced by overexploitation of the Quaternary aquifer [Erg K., 2005].

Total groundwater abstraction from the Ordovician-Cambrian aquifer system reaching about 4,700 m^3/day in 2003 have induced several local head depressions. The maximum drawdown, averaging 23 m, has been recorded at Sõrumäe. In Kiviõli the head reduction was about 10 m. The total proved reserves for the Ordovician-Cambrian aquifer system is 6,240 m^3/day (Table 31) [Savitski L., et al., 2001]. This pumping rate will induce a lowering of the head up to 1-12 m b.s.l in Kiviõli and between Mäetaguse-Pagari-Sõrumäe in 2020. Pumping of such intensity may conduce spreading of pollution in the Ordovician-Cambrian aquifer system since it is not safely protected against downward intrusions by the Ordovician basin-wide aquitard [Razgonjaev A., 1993; Rätsep A., 1999; Savitski L., et al., 2001].

The farms and small settlements mostly get their drinking water from thin Quaternary layers and Ordovician carbonate bedrock, but the unfavourable impacts of mining and aquifer pollution often affect its quality as explained above. Drying up or decreasing of water-yielding capacity of shallow wells due to dewatering of mines is an expressive example of overexploitation of upper aquifers.

The Ministry of the Environment of Estonia enforced a new determination of proved reserves of groundwater in 2003 [Põhjaveevaru hindamise…2003]. They were defined as ‘an amount of groundwater which can be used in such a way that the persistence of the good status of groundwater will be warranted’. The proved reserves must be estimated for a calculation period of 10,000 days and it must be proved that the quality class of groundwater will not change during this period [Põhjaveekogumite veeklassid…2004].

The water classes characterize the status of groundwater bodies. The good water class includes water whose quality has not been influenced or has been only weakly influenced by an anthropogenic impact. Contaminated or polluted water belongs to the bad water class. The qualitative and quantitative statuses of the groundwater body are distinguished. The general status of the groundwater body is determined by the poorer of thje two statuses.

The quantitative status of a groundwater body is good if:

- the abstraction rate is less than **the proved reserve** or less than the available groundwater resource determined at the completion of the water management plan;
- alterations in the direction of the groundwater flow caused by the changes of the groundwater table or pressure do not cause an intrusion of saline water into the groundwater body;

- a long-term trend of lowering the groundwater table or pressure does not occur or such lowering will not induce a significant worsening of the status of ecological systems associated with the groundwater body.

For the most part the statutes legislated in 2003 and 2004 are sound and they support the ideas of sustainable water consumption. However, there is one very significant exception. It is permitted to evaluate the quantitative status of a groundwater body as good if the abstraction rate from this body is less than the **proved reserve certified**. However, it is not specified how much the real groundwater abstraction should be less than the proved reserves. In such a way, from a pure juridical standpoint, proved reserves can be accepted, if they exceed groundwater abstraction, say, by a half-m^3/day, only. It means that all proved reserves certified are in force to their deadline and they are fully acceptable for an official evaluation of the groundwater status[10].

Table 31. Proved reserves and abstraction of groundwater in the study area[1)], m^3/day [Perens R., et al., 2004]

Groundwater intake	Proved reserves	Deadline	Abstraction in 2003
(1)	(2)	(3)	(4)
Quaternary deposits			
Vasavere	**10,000**	2012	**5,581**
Silurian-Ordovician aquifer system			
Kadrina	400	2025	0
Tamsalu	1,280	2025	454
Toolse, Virukivi	450	2020	117
Väike-Maarja	3,600	2020	0
Subtotal	**5,730**		**571**
Ordovician-Cambrian aquifer system			
Kadrina	150	2025	283
Kiviõli	850	2020	635
Mine ‘Estonia’	420	2020	293
Mäetaguse municipality	550	2020	162
Rakvere	3,560	2020	1,239
Tamsalu	360	2025	147
Subtotal	**5,890**		**2,759**
Cambrian-Vendian aquifer system, Voronka aquifer			
Ahtme	1,167	2012	111
Aseri	200	2020	100
Haljala, ‘Viru Õlu’	200	2024	154
Jõhvi	370	2012	71
Kadrina	42	2005	0
Kiviõli	100	2020	56
Kohtla-Järve	4,633	2012	1,956
Kohtla-Nõmme	200	2012	93
Kunda	720	2025	505
Mine ‘Estonia’	47	2020	27
Narva	1,267	2020	145

[10] The available groundwater resource will be defined in the part 3.4.4.1 of this report

(1)	(2)	(3)	(4)
Narva-Jõesuu	833	2020	308
Oru	400	2020	233
Püssi	300	2012	88
Rakvere	3,387	2020	656
Sillamäe	6,500	2020	3,325
Sirgala	500	2020	0
Sompa	467	2020	228
Toila	750	2012	37
Toolse, 'Virukivi'	17	2020	1
Viivikonna	500	2012	0
Voka	150	2020	0
Subtotal	**22,750**		**8,094**
Cambrian-Vendian aquifer system, Gdov aquifer			
Ahtme	2,233	2012	223
Aseri	600	2020	362
Haljala, 'Viru Õlu'	400	2024	307
Jõhvi	3,630	2012	1,575
Kadrina	83	2005	0
Kiviõli	3,900	2020	1,654
Kohtla-Järve	9,267	2012	3,941
Kohtla-Nõmme	400	2012	187
Kunda	1,290	2025	0
Mine 'Estonia'	93	2020	59
Püssi	700	2012	604
Rakvere	6,773	2020	1,313
Sillamäe	500	2020	65
Sompa	933	2012	455
Toila	750	2020	136
Toolse, 'Virukivi'	33	2020	3
Voka	450	2020	202
Subtotal	**32,035**		**11,086**
Total	**77,655**		**28,091**

[1)]Beginning from 2013 until 2035 will be enforced groundwater proved reserves as follows [Savitski L., Savva V., 2005]:

Groundwater intake	**Aquifer**	**Proved reserves, m^3/day**
Kohtla-Järve	Voronka + Gdov	5,970
Kohtla-Nõmme	Voronka	270
Kukruse	Voronka	170
Oru	Voronka	450
Viivikonna & Sirgala	Voronka	100
Jõhvi	Voronka	250
Jõhvi	Gdov	1,000
Püssi	Voronka	800
Püssi	Gdov	450
Ahtme	Gdov	3,300
	Total	**12,630**

3.4.4. On quantitative criteria of sustainable groundwater management

3.4.4.1. EC Water Framework Directive and groundwater bodies

For the first time the international principles of sustainable management of groundwater resources have been legislated by the Water Framework Directive (2002) of the European Community. According to this directive, the EC member states shall protect, enhance and restore all bodies of groundwater, ensure a balance between abstraction and recharge of groundwater, with the aim of achieving a good groundwater status. The groundwater body is defined as ‚a distinct volume of groundwater within an aquifer or aquifers' (Fig. 51).

The Water Framework Directive (WFD) distinguishes between the quantitative and chemical status of groundwater. The groundwater quantitative status is acceptable (good) when the long-term annual average rate of abstraction from a groundwater body does not exceed the available groundwater resource of this body. The available groundwater resource is 'the long-term annual average rate of overall recharge of the body of groundwater less the long-term annual rate of flow required to achieve the ecological quality objectives for associated surface water to avoid any significant damage to associated terrestrial ecosystems'. The level of groundwater must not be subject to anthropogenic alterations, which would result in changes in groundwater flow directions and in connections damaging the state of associated bodies of surface waters. Continuous alterations of groundwater level may occur only in spatially limited areas, but such reversals must not cause saltwater or other intrusions. Changes of the groundwater movement must not indicate a sustained and clearly identified anthropogenically induced trend in flow directions that can engender harmful intrusions. Groundwater chemical status is good when it does not exhibit the effects of saline or other intrusions, does not exceed the quality standards, and does not restrain the achievement of the environmental objectives in the surface waters associated with bodies of groundwater.

The implementation of the principles of the WFD is compulsory for Estonia as a member of the European Community. In this connection, the new modernized formulation of groundwater proved reserves and a delineation of groundwater bodies in Estonia were enforced by the Ministry of Environment [Põhjaveekogumite veeklassid...2003; Põhjaveevaru hindamise...2003]. A groundwater body is not a basin-wide unit of hydrogeological stratigraphy, but rather a subdivision of a hydrogeological unit or units preceding from the objectives of the water management straregy. In Estonia, 15 groundwater bodies have been distinguished. The study area with its groundwater-bearing formation has been divided into eight groundwater bodies [Põhjaveekogumite veeklassid...2003; Viru-Peipsi Catchment…2004]. The main characteristics of these groundwater bodies are presented in Table 32.

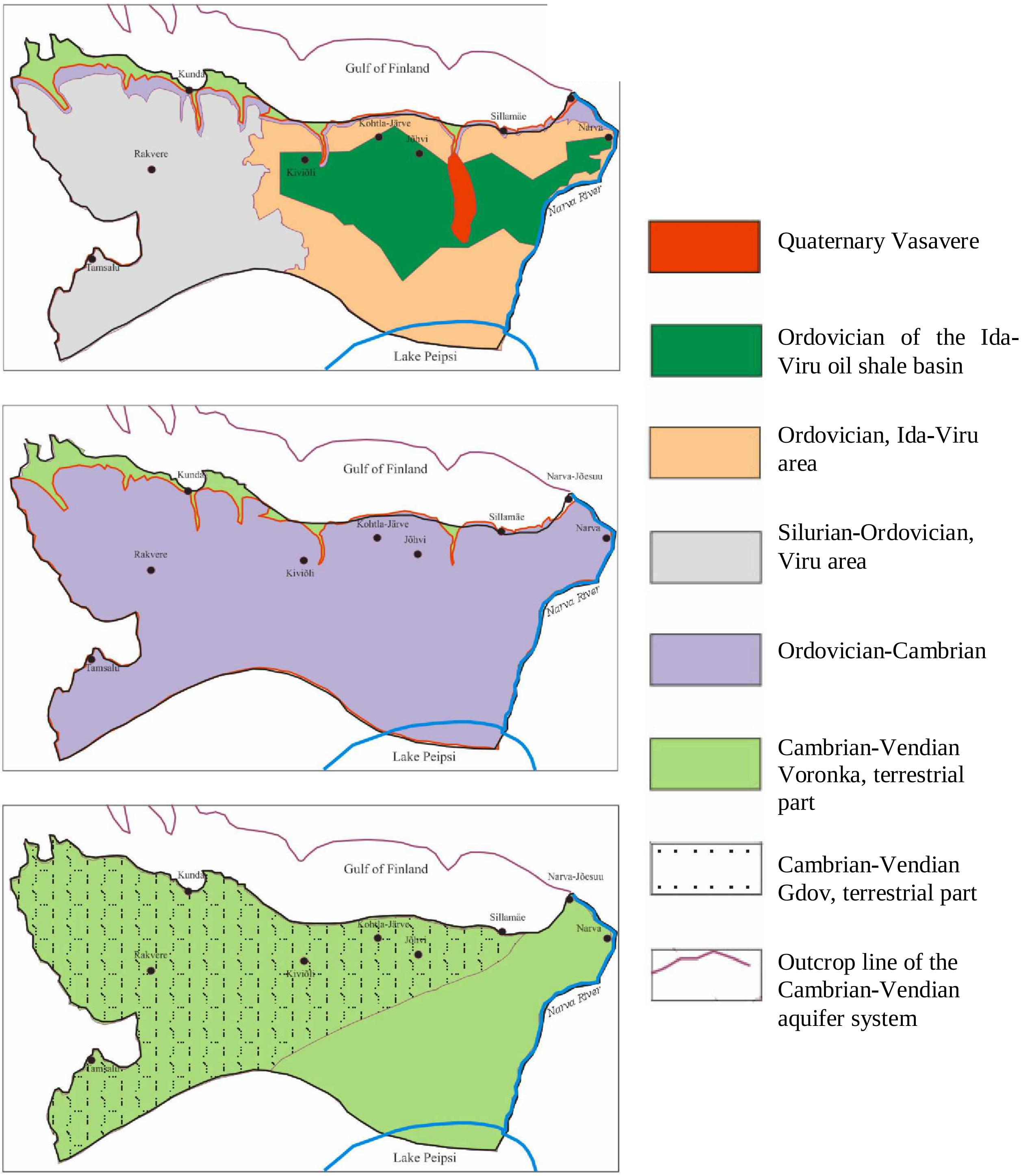


Figure 51. Groundwater bodies [Viru-Peipsi Catchment…2004]

Table 32.Groundwater bodies in the study area [Viru-Peipsi Catchment…2004].

Groundwater body and its area	Geology	Consumption and stresses	Chemical status
Quaternarian Vasavere groundwater body, 80 km^2	Sands and gravels	Consumed in Ahtme and Jõhvi, endangered by mining activities	High content of Fe and NH_4, low pH and high permanganate oxidation, SO_4 content reaches 260 mg/l
Middle and Lower Devonian groundwater body, 300 km^2	Sandstones, aleurolites and dolomites	Water consumption is insignificant, endangered by mining activities	Meets the requirements of drinking water in general
Ordovician Ida-Viru groundwater body, 2,043 km^2	Limestones and dolomites, highly karstified and fissured	Source of water supply for the sparse rural population in the Ida-Viru County, especially in its southern part	High NH_4 content, low pH and high permanganate oxidation
Ordovician groundwater body of the Ida-Viru oil shale basin, 1,154 km^2	Limestones and dolomites, highly karstified and fissured, contains the commercial bed of oil shale	Unfit for drinking water supply because of pollution, potential pollution source for another groundwater bodies	Chemical status is poor. In nearly 20% of studied points concentration of SO_4 exceeds 250 mg/l, TDS reaches 1 g/l, hardness is 10-16 me/l
Silurian-Ordovician aggregated groundwater body, 1,738 km^2	Limestones and dolomites, highly karstified and fissured	Source of water supply for the sparse rural population in the Lääne-Viru County	Meets the requirements of drinking water in general
Ordovician-Cambrian groundwater body, 5,475 km^2	Sandstones and aleurolites	It is consumed in towns of Ida and Lääne-Viru Counties and in sparsely populated areas. Crosses the border of Estonia and has been influenced by water consumption in both Estonia and Russia being an international groundwater body.	NH_4 concentration exceeds the drinking water standard in 13 % of the wells, concentration of SO_4 exceeds 250 mg/l in places, sporadically contaminated

Cambrian-Vendian Voronka groundwater body, 5,475 km^2	Sandstones and aleurolites	Consumed everywhere in the study area, in coastal region often the only groundwater body usable for public water supply. Crosses the border of Estonia and has been influenced by water consumption in both Estonia and Russia being an international groundwater body	Not vulnerable to pollution coming from overlying strata. Saline seawater can intrude into coastal production wells; upconing of brines from the Gdow aquifer is possible.
Cambrian-Vendian Gdov groundwater body, 3,621 km^2	Sandstones and aleurolites	Consumed everywhere in the study area	Not vulnerable to pollution coming from overlying strata. Natural high concentration of Cl and Na, high radioactive effective dose, in 24% of wells NH_4>0,5 mg/ml. Chloride concentration higher than drinking water standard eastward of Kohtla-Järve. Brines from deeper strata and saline seawater can encroach. It is recommended to use only as technical water in future.

3.4.4.2. Methodological background

According to the main standpoints of the WFD, it is necessary to estimate available groundwater resources of groundwater bodies and to compare them with groundwater abstraction. If the abstraction exceeds the available resource calculated then the quantitative state of the groundwater body under consideration should be assessed as a bad one.

Since the available groundwater resources are estimated by this work for the first time in Estonia, some complementary explanations are in order. As a simplified formulation, the available resource of a groundwater body is its long-term average recharge less the amount of water needed for supporting the acceptable status of associated surface ecological systems (rivers and wetlands in our case). This definition is appropriate enough to determine the available resource for a groundwater basin consisting only of a single layer. On the contrary, if the groundwater bodies (aquifers) are layering on top of each other, forming a multi-layer system, then the mode of estimation of the available resource needs some development. In the multi-layer conditions, the resource of an upper aquifer must also guarantee the available resources of underlying aquifers. Therefore, the available resource of an overlying layer must be less the amount of water spent for the formation of available resources for underlying layers.

The WFD does not indicate exactly how to understand the term ‘long-term average recharge’. Is it natural recharge of aquifers in predevelopment conditions or is it recharge during a long-term abstraction period including induced recharge? Induced recharge directly depends on the pumping rate, which can be too intensive from the standpoint of sustainable groundwater consumption. Therefore, it is logical to decide that induced recharge must not to add to the amount of water forming the available resource of an aquifer. Because of this, below, the available resource of a groundwater body is estimated on the basis of its natural recharge components in predevelopment conditions.

It is important to point out that it is not possible to capture the whole amount of water forming the available resource of a groundwater body by production wells without causing head drawdowns. These drawdowns, depending on hydrogeological setting, can engender or not engender unfavourable intrusions into the groundwater body.

The best way to assess the sustainable resource of a groundwater body belonging to a multi-aquifer system is to use the capabilities of a well-calibrated basin-wide hydrogeological model. The first step should be determination of undesired intrusions that would be induced by a real or planned groundwater abstraction rate. This enables an optimum distribution of drawdowns not causing or minimizing unfavourable intrusions into the groundwater body under consideration to be determined. In the second step of investigation, such pumping rates should be assigned to existing production wells that do not force the groundwater pressure to lower more than the maximum drawdown permitted (some modelling codes render it feasible to directly assign to wells an acceptable drawdown). The procedure described must be carried out for every layer of the aquifer system using the trial and error method. It demands the performance of a great number of model simulations. The optimum pumping rates calculated can be considered as the sustainable yield of layers (aquifers) according to the existing placement of groundwater intakes.

The basin-wide hydrogeological model of Estonia has been used to estimate the groundwater available resources and to carry out detailed water budget investigations of the study area. The domain of this model, all together 88,032 km^2, includes the territory of Estonia with surrounding portions of the Baltic Sea and the Gulf of Finland, Lake Peipsi and border districts of Russian Federation and Latvia [Vallner L., 2002, Vallner L., 2003]. The 13 model layers include all main aquifers and aquitards from ground surface to as low as the impermeable part of the crystalline basement.

The latitudinal diameter of the model domain is 420 km and its extent in the meridional direction – up to 252 km. A three-dimensional flow and transport model of this area was constructed. The model has been converted to the code Visual MODFLOW v. 4 [2004]. The latter is based on a finite-difference solution of equation [McDonald M.-G., 1988]:

$$(\partial/\partial x)(K_{xx}\partial h/\partial x) + (\partial/\partial y)(K_{yy}\partial h/\partial y) + (\partial/\partial z)(K_{zz}\partial h/\partial z) - W = S_s\, \partial h/\partial t.$$

Here K_{xx}, K_{yy} and K_{zz} are values of hydraulic conductivity along the *x, y* and *z* coordinate axes [LT^{-1}]; h is the potentiometric head [L]; W is the volumetric flux per unit volume and represents sources and/or sinks of water [T^{-1}]; S_s is the specific storage of the porous material [L^{-1}]; and t is time [T].

The recharge of groundwater on the top of the model was given as the net infiltration I (total groundwater recharge minus evaporation from the zone of saturation or capillary fringe). It has been calculated preliminarily from the budget equation comprising the main components of groundwater flow [Vallner L., 1997, Vallner L., 1980]:

$$I = R + P + M - A \pm V \pm S$$

where R is the groundwater discharge (base flow) to streams; P is the pumping from layers; M is the direct seepage of groundwater to the sea; A is the flux from streams into aquifers (induced recharge, mostly in the vicinity of mines); V is the subsurface exchange of groundwater between the study area and the surrounding region and S is the storage change.

The long-term groundwater discharge into streams R and flux A have been estimated on the basis of observations carried out during several decades at more than 100 hydrological gauging stations all over the area modeled. Apart from the gauging stations, many irregular measurements of the low flow have been made approximately in 1000 stream cross-sections. The gained sporadic low flow data were modified to average base flow value by statistical methods using regular observations of gauging stations. A detailed map of the base flow at a scale of 1:200,000 for the study area was compiled by L. Vallner [1976]. The pumping data P were obtained from state institutions checking the groundwater use. The subsurface fluxes to sea M and groundwater exchange with adjacent areas V were calculated by Darcy's formula.

Groundwater discharge to the river network and the instrumentally checked pumping make up about 90% of the sum of the right side in the above water budget equation. Therefore, the value of the net infiltration estimated by the budget equation is more authentic than that based on indirect data, such as the air temperature and atmospheric humidity, evapotranspiration *etc.* that are often used for calculation of net infiltration by empirical formulas.

The model was calibrated against two different sets of calibration targets – one set representing the measured elevation of groundwater table and head, averaged to 2003, and another set corresponding to the base flow of the river network. The base flow data reflects the minimal river runoffs observed at stream gauging stations during 30 days of a dry-weather-period every year and they have been averaged to long-term rates [Resursy poverhnostnyh…1972]. Using different kinds of calibration targets enhances the authenticity of modeling results and especially the adequacy of budget calculations. The averaged pumping data of 2003 were incorporated to the model for its calibration, too.

To restore the predevelopment conditions of groundwater consumption, all groundwater intakes were deactivated in the calibrated model and a corresponding distribution of the heads $h(x, y, z)$ was simulated. The latter was considered as a mathematically correct base for calculating of predevelopment water budgets. The water budget of 2003 was calculated by the model in which the production wells operated with the pumping rates of 2003.

To calculate the groundwater budget of the study area, a number of water budget zones were specified in the each layer of the hydrogeological model of Estonia. The transversal and lateral fluxes were estimated for every budget zone and detailed water budgets of aquifers and groundwater bodies were completed. It gave a possibility to estimate the available resources of groundwater bodies.

Having estimated the available resource of every groundwater body considered, a possibility arises to compare the available resource with actual and planned groundwater withdraw. The quantitative requirement of the WFD can be formulated mathematically as follows:

$$B \le D \tag{1}$$

$$Q \le D \tag{2}$$

Here B is the average abstraction rate from the groundwater body in 2003; Q is the proved reserve for the latter and D is the available resource.

The condition (1) expresses the WFD demand that the abstraction rate must not exceed the available groundwater resource. If (*B/D*)>1 then the abstraction is more than the available resource. and in accordance with WFD the status of the groundwater body is bad. Apparently, the same is valid for the proved reserve, too (2). The expression (*Q/D*)>1 means that the proved reserve certified exceeds the available resource and, consequently, the planned groundwater withdraw is not allowed from the standpoint of the WFD.

3.4.4.3. Available groundwater resources and the quantitative status of groundwater bodies

Preceding from the above principles, the budget zoning of the completed model was carried out at first. The groundwater bodies were distinguished from the other water bearing layers as the special budget zones. Then all wells were deactivated and a detailed water budget of each groundwater body was obtained for the predevelopment (natural) conditions by the model calculations (Table 33). After that, analysis and estimation of the available resources was begun, starting from the lowermost groundwater bodies.

From Table 33 it appears that the total inflow into the Cambrian-Vendian Gdov groundwater body is 7,100 m^3/day (the numbers have been rounded at the budget analysis) in the predevelopment conditions. At first sight it seems that the all outflow from the terrestrial part of the Gdov groundwater body, reaching 6,500 m^3/day, can be intercepted, but then the head would be below the sea level in the aquifer and the saline water will intrude toward the coastal intakes. Apparently, a head value exceeding the sea level, say, by 1 m, must be preserved in the centres of main groundwater intakes in all events. To achieve this situation, new smaller pumping rates were assigned for wells tapping the Gdov aquifer in the model. Suitable well yields, which lowered the groundwater head to the absolute height +1 m in the centres of main intakes, were established using the trial and error method at simulations. As a result it was discovered that the total withdraw from the Gdov aquifer that will not cause a saline water intrusion in the study area is approximately 5,000 m^3/day. Obviously, this pumping rate is equal to the available resource of the Gdov groundwater body. In this case a groundwater flow from the terrestrial part of the Gdov aquifer into its submarine part, of about 700 m^3/day, is preserved.

The same procedure was carried out for the Cambrian-Vendian Voronka groundwater body. It was calculated that the available resource of this groundwater body is 3,000 m^3/day at a minimum decline of the head towards the sea to prevent the saline water intrusion.

At the Ordovician-Cambrian groundwater body it was essential to preserve the downward flux into the underlying Voronka aquifer of about 3,500 m^3/day that occurs in predevelopment conditions. Taking into account this restriction and supposing that almost all the remaining portion of the outflow may in principle be intercepted, the available resource of the Ordovician-Cambrian groundwater body is approximately 20,000 m^3/day. This conclusion derived from the water budget analysis was confirmed by model simulations.

Table 33. Predevelopment water budget of groundwater bodies and their available resource, m^3/day

Groundwater body	Inflow				Outflow					Available groundwater resource
	From above	Lateral	From below	Total in	Up	Lateral	Down	Into channel network	Total out	
Quaternary Vasavere	21,600 (infiltration)	13,300	0	34,900	0	8,000	300	26,600	34,900	8,000
Ordovician of the Ida-Viru oil shale basin	239,400 (infiltration) + 300	79,700	300	319,700	0	116,000	1,400	202,300	319,700	104,000
Ordovician, Ida-Viru area	288,400 (infltration)	225,200	2,800	516,400	0	208,500	8,300	299,600	516,400	208,000
Silurian-Ordovician, Viru area	763,300 (infiltration)	98,800	600	862,700	0	166,500	16,500	679,700	826,700	167,000
Ordovician-Cambrian	26,200	1,000	0	27,200	4,200	3,200	5,000	14,800 (spring discharge on Klint)	27,200	20,000
Cambrian-Vendian Voronka, terrestrial part	3,500	2,200	500	6,200	<100[1]	3,100	3,100	0	6,200	3,000
Cambrian-Vendian Gdov	3,000	4,100	0	7,100	600	6,500	0	0	7,100	5,000

[1]Flow rate <100 m^3/day has not been accounted at summation.

The available resource for the upper groundwater bodies was estimated accordingly to the WFD definition. It was determined as the long-term natural recharge of the groundwater body minus the flow rates needed for supporting the good statuses of associated surface ecological systems and of the underlying Ordovician-Cambrian groundwater body. It is not indicated what amount of groundwater should ensure the good status of surface water and other terrestrial ecological systems [Viru-Peipsi Catchment…2004], but in the present investigation, it has been supposed that besides a certain portion of the surface runoff, the whole base-flow would be used for this purpose. Due to a significant inflow, reaching in total about 1,700,000 m^3/day, the available resources of the three bigger groundwater bodies, connected chiefly with carbonate bedrock, exceed the available resources of Cambrian-Vendian sandstones by 10-20 times (Table 33). The available resource of the Vasavere groundwater body belonging to the Quaternary sand and gravel is about 8,000 m^3/day. At this well yield, the lowering of the water table of theb Kurtna Lakes will remain in an acceptable range (if the drainage effect of surrounding mines and quarries is not incorporated to the pumping impact of the Vasavere groundwater intake).

The available resources, the proved reserves, and the actual abstraction for every groundwater body studied (Tables 31, Table 33) have been juxtaposed in Table 34. According to the estimations carried out, the present abstraction is less than the available resource, and consequently acceptable, for the Quaternarian Vasavere, Silurian-Ordovician (Viru area), and Ordovician-Cambrian groundwater bodies. Their proved reserves are suitable, except for the proved reserve certified for the Vasavere groundwater body. It is feared that a permitted pumping rate reaching 10,000 m^3/day will cause an unfavourable lowering of the water table of some lakes in the vicinity of Vasavere intake. The amount of water pumped out from mines and quarries exceeds the available resource of the Ordovician carbonate bedrock in the Ida-Viru oil shale basin more than five times and the abstraction from the Cambrian-Vendian Voronka and Gdov groundwater bodies is two-three-fold more than the proved reserves. The application resources certified for Cambrian-Vendian groundwater bodies exceed their proved reserves by five - six times!

The groundwater budget analysis above demonstrates that the quantitative status of the Ordovician groundwater body in the Ida-Viru oil shale basin, as well as the quantitative statuses of Cambrian-Vendian Voronka and Gdov groundwater bodies are bad in Northeast Estonia. The allowed maximum pumping rates (proved reserves) are overestimated for the Quaternarian Vasavere groundwater body and especially for Cambrian-Vendian Voronka and Gdov groundwater bodies. These findings form a contrast with the position of the research carried out by the Ministry of Environment of Estonia [Viru-Peipsi Catchment…2004] in which the statuses of the same Voronka and Gdov groundwater bodies were evaluated as good ones.

Table 34.Water management characteristics of groundwater bodies, m^3/day

Groundwater body	Available groundwater resource *(D)*	Abstraction in 2003 *(B)*	Proved reserve *(Q)*	Ratio *P/D*	Ratio *Q/D*
Quaternary Vasavere no 13	8,000	5,581	10,000	0.70	1.25
Ordovician of the Ida-Viru Oil shale basin	104,000	556,227	Not determined	5.35	No data
Ordovician, Ida-Viru area	208,000	No data	Not determined	No data	No data
Silurian-Ordovician, Viru area	167,000	28,585	6,230	0.15	0.04
Ordovician-Cambrian	20,000	2,759	6,640	0.14	0.32
Cambrian-Vendian Voronka, terrestrial part	3,000	8,084	32,035	2.70	6.20
Cambrian-Vendian Gdov, terrestrial part	5,000	11,086	22,750	2.22	4.60

4. Economics of Estonian oil shale industry

4.1. Cost price structure of oil shale products and services

The structure of oil shale cost price and electricity cost price from oil shale and the share of environmental charges in oil shale price and electricity price are considered in this chapter.

4.1.1. Cost price of oil shale extraction

The average cost of saleable oil shale was about 122 EEK/tonne in 2002, which is 7.8 EURO. (1EUR=15.6466EEK, 1sent=0.01EEK). The oil shale price has increased 6 times from 1992.

The major share of the **expenses of oil shale mining** consists of labour costs (42.5%) – see Table 35. In the 2002/2003 financial year, 4,666 workers worked for "AS Eesti Põlevkivi", the average salary was 7,836 EEK (501€) [Appendixes of annual bookkeeping…, 2003]. The share of materials in the structure of "AS Eesti Põlevkivi's" expenses was 17.6%, the major parts of which were costs of explosives (62.3%), different materials (23.2%), and metals and metallic wares (11.8%).

Table 35. "AS Eesti Põlevkivi" expenses in 2002 [Appendixes of annual bookkeeping…, 2003]

	1000 EEK	%
Materials	246,557	17.6%
Transport cost	18,985	1.4%
Fuels	75,436	5.4%
Electricity	124,370	8.9%
Heat	3,717	0.3%
Labour cost	596,611	42.5%
Resource and pollution charges	84,365	6.0%
Others	253,581	18.1%
Total expenses	1,403,623	100%
Establishment and reduction of mining termination and environmental charges provision	29,960	
	1,433,583	

The share of environmental taxes in the cost price of oil shale mined was (and is currently) about 6%, the share of expenses for oil shale resource use (is included into environmental taxes) was 4.4% from the total expenses of "AS Eesti Põlevkivi".

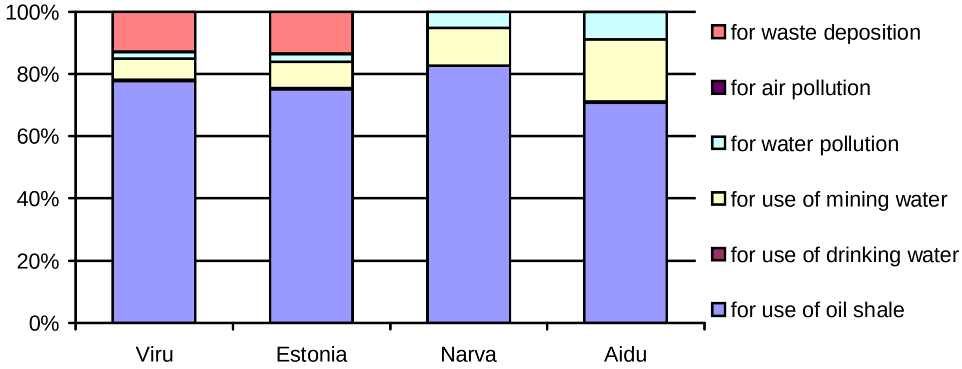


Figure 52. The structure of environmental charges of mining enterprises, 2002.

As seen from Figure 53, the main share, 77%, of environmental taxes, or 63,370 thousand EEK, consisted of the charge for the use of oil shale. The total charge for use of mining water was 8,802 thousand EEK or 11% of the total environmental charges (160 million m^3 of water per year). About 8% (6,590 thousand EEK) of the total environmental charges was for solid waste deposition (3,940,095 tonnes of enrichment waste).

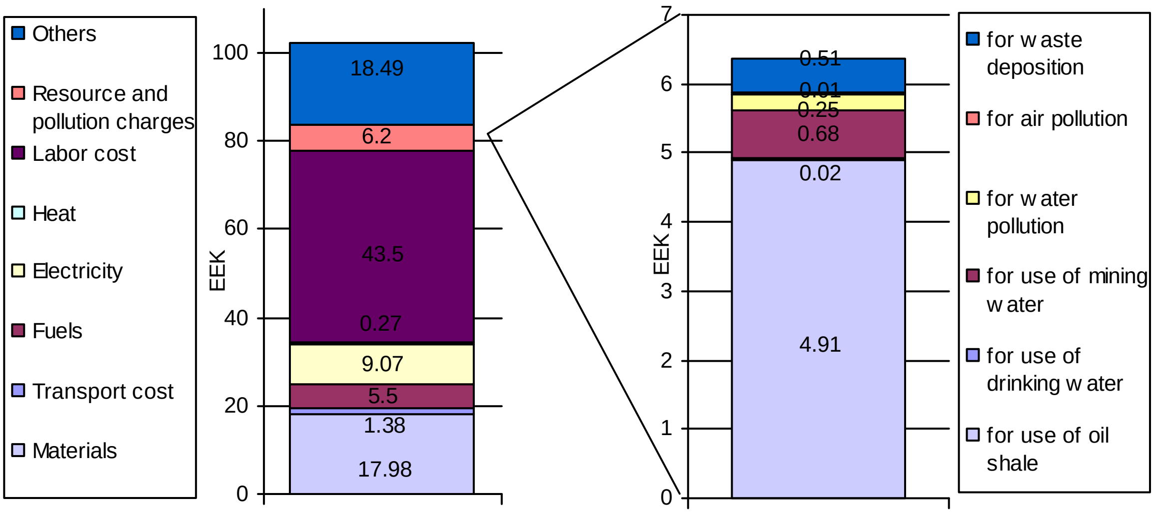


Figure 53. The expenses of “AS Eesti Põlevkivi” per one tonne of oil shale, EEK (cost price of 1 tonne of oil shale was 102.3 EEK).

4.1.2. Cost price of electricity and heat generation from oil shale

The structure of the expenses of electricity and heat production (Table 36) was presented by “AS Eesti Energia” [Eesti Energia annual…, 2003]. The data were presented for financial year 2002/2003. Unfortunately the data of the expenses are presented in the Report for total (unspecified) electricity production and for total heat production for all power plants (Narva PPs, Kohtla-Järve CHPs and Iru CHP), which makes it difficult to trace the data. The environmental expenses of electricity and heat generation are not presented separately in the Reports of the company, and they were included into “operational expenses”. Therefore we had to calculate the detailed environmental taxes ourselves using the available data.

Table 36. The expenses of electricity and heat production, 2002 [Eesti Energia annual…, 2003]

	1000 EEK		sent/kWh
Goods provided outside system	842,184	24.1%	8.37
Goods, materials, services provided inside system	1,582,612	45.2%	15.73
Operational expenses	413,779	11.8%	2.12
Environmental expenses[11]	200,538	5.7%	1.99
Labor cost	297,364	8.5%	2.96
Others	3,968	0.7%	0.04
Amortization	337,628	9.6%	3.36
Total	**3,499,362**	**100.0%**	**34.79**

As seen from Table 36, the major part (45.2%) of the expenses consists of the costs of goods, materials and services provided inside the system. This sum mostly includes the payment for oil shale bought from "AS Eesti Põlevkivi" (oil shale for Narva PPs and Kohtla-Järve CHPs was sold for the sum of 1,482,860 EEK [www.ep.ee].

As seen from Table 37 the average (Narva PPs, Kohtla-Järve CHPs and Iru CHP) environmental charges were only 1.99 sent/kWh or 5.7% of the total sum of expenses for electricity and heat generation. The structure of the environmental charges for Narva PPs and Kohtla-Järve CHPs is presented in Table 37.

Table 37. The structure of environmental cost of Power Plants in 2002

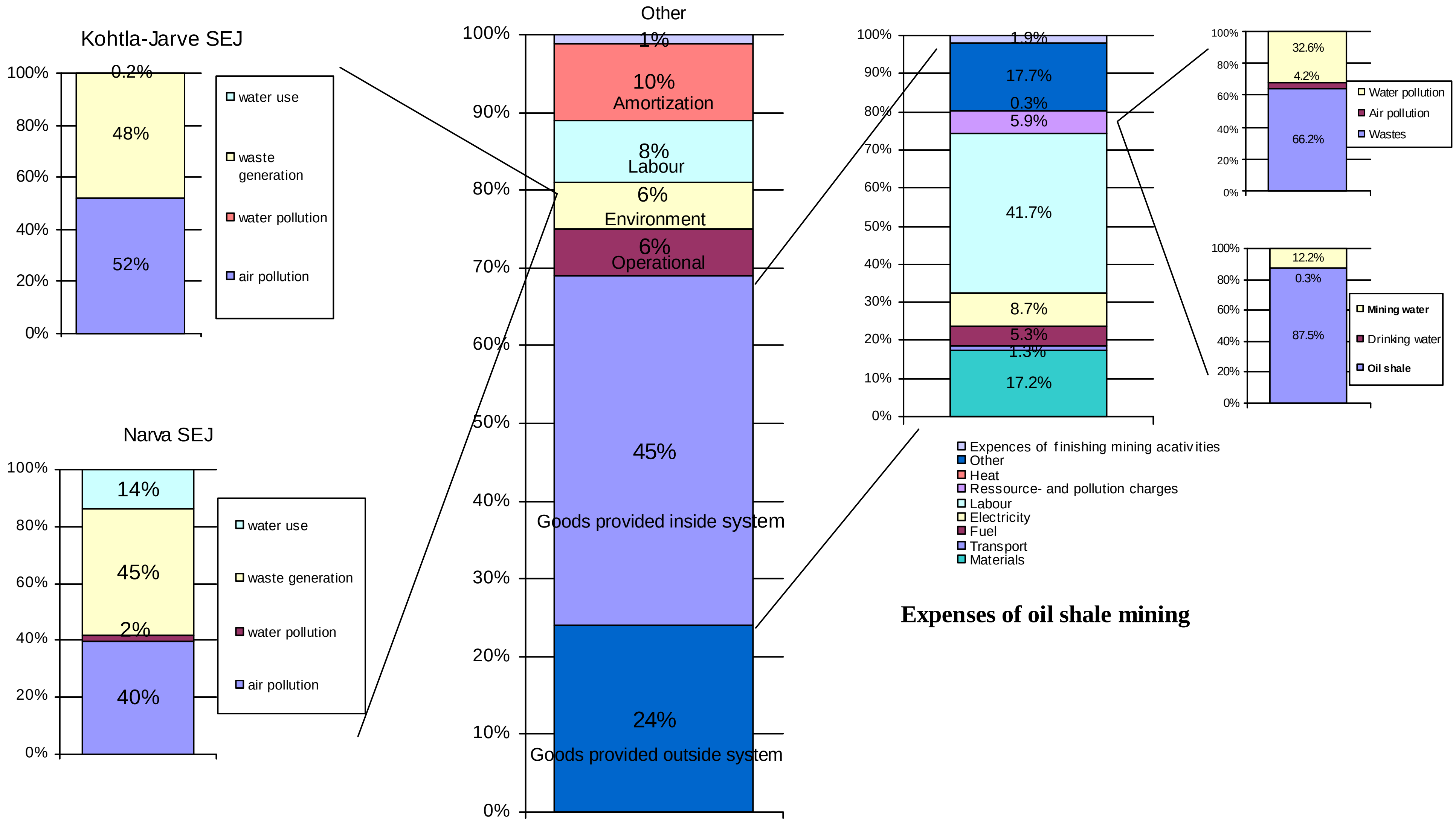
	Narva PPs		Kohtla-Järve CHPs		Total	
	EEK	sent/kWh	EEK	sent/kWh	EEK	sent/kWh
Charge for air pollution, 1000 EEK	**76,950**	**0.99**	**2,997**	**0.49**	**79,947**	**0.95**
SO_2, EEK	4,842,858	0.06	340,073	0.06	5,182,931	0.06
NO_X , EEK	1,796,886	0.02	60,364	0.01	1,857,250	0.02
Particulates, EEK	1,944,427	0.02	37,070	0.02	1,981,497	0.02
CO, EEK	179,058	0.002	678	0.0001	179,736	0.002
H_2S, EEK	12		0		12	
Phenols, EEK	819	0.00001	546	0.00009	1,365	0.00002
CO_2 equiv.balance with CH_4, EEK	68,186,355	0.9	2,558,228	0.4	70,744,583	0.84
Volatile Organic Compounds, EEK	0		24	0.000004	24	
Charge for oil shale ash deposition, 1000 EEK	**86,721**	**1.11**	**2,731**	**0.45**	**89,452**	**1.06**
Charge for use of water, 1000 EEK	**27,289**	**0.352**	**10**	**0.002**	**27,299**	**0.32**
As cooling water, EEK	27,129,525	0.35	10,375	0.002	27,139,900	0.32
From wells, EEK	159,284	0.002			159,284	0.002
Charge for water pollution, 1000 EEK[12]	**105**		**3**		**108**	**0.005**
Amount of effluent, EEK	?		?			
Suspended solids, EEK	60,581	0.001	937	0.0002	61,518	0.001
Total nitrogen	16,444	0.0002	245	0.00004	16,689	0.0002
Phosphorus	3,233	0.00004	245	0.00004	3,478	0.00004

[11] according to our calculation for 2002 calendar year

[12] was estimated using the data [Laur A., et al., 2004a] in the further calculations

	EEK	sent/kWh	EEK	sent/kWh	EEK	sent/kWh
Sulphates	24,872	0.0003	2,034	0.0003	26,906	0.0003
Total, 1000 EEK	**191,353**	**2.5**	**5,741**	**0.9**	**197,094**	**2.34**

The environmental charges from Table 37 were estimated by us, taking into account annual emissions into air and water of substances and the charge for air pollution, oil shale ash deposition and for use of water. Only the charge for releasing effluents into a water source (3,907,000 m^3 at Narva PPs and 174,000 m^3 at Kohtla-Jarve CHPs) was not estimated by us, as the amount of polluted water contained different contaminants, and these were not presented in the data sources available to us. However, Laur A. [Laur A., et al., 2004a] had estimated that the charge for water pollution of Narva PPs in 2002/2003 financial year was 393 thousand EEK, and this number was used by us in further calculations.



Expenses of oil shale mining

Expenses of electricity and heat production

Figure 54. The structure of expenses of oil shale mining and energy production

4.1.3. Estonian environmental taxes

Environmental costs in the price of oil shale and energy are only 5.9% and 6% of the respective cost prices (Fig. 54). The main reason for this is the low environmental charges for the oil shale mining and processing industry. The tariffs for the oil shale industry are considerably lower than for other producers in Estonia, and remarkably lower than for the producers in neighbouring countries (Latvia, Poland etc.). Tables 38, 39, 40 and Figure 55 illustrate some environmental charges.

Table 38. The charge rate for use of oil shale resource and waste disposal, EEK/tonne [Mining charge rates..., 2001; Pollution charge act, 1999, 2001]

	1999	2000	2001	2002	2003	2004	2005
Charge for use of oil shale resources	4.0	4.0	4.8	4.8	4.9	5.1	5.2
Charge for oil shale dirt disposal	0.6	0.9	1.3	1.6	1.9	2.0	3.0
Charge for oil shale ash disposal	1.9	2.9	4.2	4.4	4.6	4.9	5.1
Charge for semi-coke disposal, fuse	5.2	7.8	11.2	13.4	16.0	19.0	23.0

The charge for use of oil shale is comparable with the charges for use of sand and other construction materials (see [Mining charge rates..., 2001]).

As it was noted, the main types of waste from oil shale industry are, according to European Commission Decision 2000/532/EC (European Waste Catalogue and Hazardous Waste List), hazardous wastes. However, the cost for disposal of hazardous wastes for oil shale industry is lower than those for other industries. For example, the charge for disposal of hazardous waste from other industries is 8.4 EEK/t[13] which is 5.3 times more than the charge for disposal of oil shale dirt and 1.9 times higher than that for oil shale ash storage. It should be acknowledged, however, that additional charges are in some cases applied due to unsatisfactory dumping conditions.

The price of mining water and the cost of cooling water are very low – 5.5 sents/m^3 and 2.5 sents/m^3 accordingly (Table 39). The tax rate for consuming groundwater collected from mines and quarries is 8 times smaller than the tax for groundwater intake for other consumers (5.5 and 44 sents/m^3 respectively). Cooling water used by power plants is 6 times cheaper than surface water intake by “ordinary” consumers (2.5 and 15 sents/m^3 respectively).

Table 39. Charge rates for use of water, sent/m^3 [Charge rates for special use…, 2001]

	1999	2000	2001	2002	2003	2004	2005
Reservoirs of Tallinn and Kohtla-Järve towns	20	25	30	30	30	32	33
taking cooling water from it	2.5	3	3.5	4.0	4.0	5.0	5.0
other reservoirs	10	12	14	15	17	19	20
Cooling water from other areas	2	2.5	2.5	2.5	2.5	2.5	2.5
2. Groundwater							
Quaternary (Q)	20	25	30	33	36	40	44
Upper-, Middle-Devonian (D); Middle-Devonian-Silurian (D-S); Silurian - Ordovician (S-O); Ordovician - Cambrian (O-E)	30	35	40	44	48	53	59
Cambrian-Vendian (E - V)	35	40	45	50	54	60	66

[13] Hazardous waste – 8.4 EEK/t; Naphtha, mineral oil and solid fuels and other organic substances from thermal operating etc. – 22.6 EEK/t; [Pollution charge act, 2001]

	1999	2000	2001	2002	2003	2004	2005
Pumping of water from Cambrian-Vendian for technological consumption			80	88	97	106	117
4 Groundwater pumping for water layer reduction (for carrying out of extraction work at opencast and underground mining)	3.0	4.0	5.0	5.5	6.0	6.5	7.0

CO_2 tax – 7.5 EEK/t was just symbolic in 2002. Current CO_2 tax (valid since 01. January 2005) is 11.3 EEK/t (Table 40). The tax rate of CO_2 used in the trade of the emission quota was proposed as 17 EUR (266 EEK, 35 times higher). SO_2, NO_x etc taxes are in Estonia tens of times lower than in neighbouring (Nordic) countries (Fig. 55).

Table 40. Air pollution charge rates, EEK/t [Pollution charge act, 1999, 2001]

	1999	2000	2001	2002	2003	2004	2005
Sulphur dioxide (SO_2)	46.0	55.2	66.2	79.0	95.0	114	137
Carbon monoxide (CO)	6.6	7.5	9.5	11.0	14.0	16.0	20.0
Particulates	46.2	55.2	66.2	79.0	95.0	114	137
Volatile Organic compounds (VOC)	42.8	51.5	61.9	182	218	262	315
Nitrogen oxides (NO_x)	105.4	126.4	151.7	182	218	262	315
Carbon dioxide (CO_2)		5	7.5	7.5	7.5	7.5	11.3

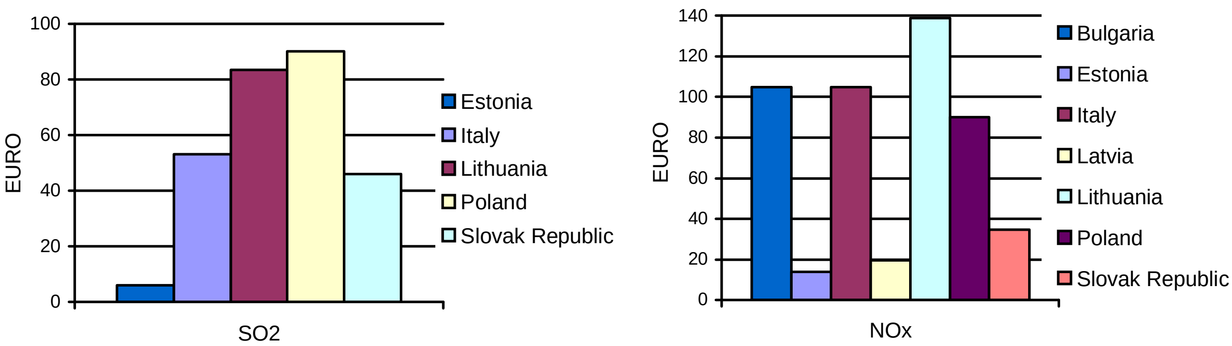


Figure 55. SO_2 and NO_X taxes by countries in 2003, €/tonne [Environmentally Related Taxes database].

Increasing of environmental taxes to a comparable level with other industries would have a substantial influence on the cost price of oil shale and produced electricity (see Tables 41 - 44). After assumed "harmonization", resource- and pollution charges per 1 tonne of mined oil shale should increase about 2 times (current level is 6.15 EEK/t). Increase of oil shale cost price due to the assumed increase in environmental expenditures for mining would not be substantial (from 104 to 110 EEK). However, if the cost prices for electric and thermal energy were also raised, the oil shale cost price would be about 120 EEK/t (Table 41).

Table 41. Cost price structure of oil shale with the current tax rates, and after assumed increase of environmental taxes

Cost price structure of oil shale	Current in 2002		After increasing environmental taxes	
	EEK/t	%	EEK/t	%
Materials	17.98	17.2	17.98	14.9
Transport cost	1.38	1.3	1.38	1.1
Fuel	5.5	5.3	5.50	4.6
Electricity	9.07	8.7	18.14	15.0
Labour cost	43.5	41.6	43.50	36.1
Resource and pollution charges	6.15	5.9	12.84	10.7
Heat	0.27	0.3	0.54	0.4
Other	18.49	17.7	18.49	15.3
Finishing of mining activities	2.18	2.1	2.18	1.8
Total	104.52	100.0	120.55	100.0

Table 42. Current environmental tax rates and predicted increase after "harmonization" with other industries

Resource and pollution charges by mining	Current price, EEK/tonne	Predicted increase, times	New price, EEK/tonne
Oil shale (production + losses)	4.6	1	4.62
Drinking water	0.0	1	0.02
Mining water	0.6	8	5.12
Water pollution	0.2	1	0.24
Air pollution	0.0	1	0.01
Dumping of wastes	0.5	5.25	2.52
Total	6.15	17.3	12.5

Assumed increase of taxes for CO_2, water consumption and for land use for mining and dumping of wastes, with the purpose of harmonizing the rates for different industries, would raise environmental costs from the current 2.5 Estonian sent/kWh to up to 36 sent/kWh for electricity generation, causing a 2 fold increase in the cost price (to about 80 sents per kWh). A possible more than 2-fold increase in the cost price would increase the cost price of oil shale electricity to a level that would be un-competitive with other fuels. The assumed increase in environmental taxes should increase the cost of oil shale electricity in Estonia (in absolute units) above that in such wealthy neighbour states as Sweden or Finland (Fig.1-4 in Appendix VIII).

Table 43. Increase in the cost of electricity due to assumed increase in environmental taxes

Cost price structure of oil shale electricity	Structure in 2002		After assumed increasing of environmental taxes	
	sent/kWh	%	sent/kWh	%
Other expenditures	0.26	0.7	0.26	0.4
Amortization	3.36	9.7	3.36	4.7
Labour expenditures	2.96	8.5	2.96	4.1
Environmental expenditures	2.06	5.9	36.34	50.3
Operational expenditures	2.06	5.9	2.06	2.9
Goods provided inside OS system	15.73	45.2	18.876	26.1
Goods provided outside OS system	8.37	24.1	8.37	11.6
Total	34.8	100.0	72.23	100.0

Table 44. Environmental taxes for electricity generation from oil shale

Environmental taxes for electricity generation from oil shale	Current, sent/kWh	Predicted increase, times	New tax rates, sent/kWh
SO_2 (atmosphere)	0.06	5.00	0.30
NOx (atmosphere)	0.02	5.00	0.10
Particulates (atmosphere)	0.02	5.00	0.10
CO (atmosphere)	0.002	5.00	0.01
Phenols (atmosphere)	0.00001	5.00	0.00
CO_2 (with CH_4)	0.90	**35.00**	31.50
Oil shale ash deposition	1.11	2.00	2.22
Water use	0.35	6.00	2.10
Water pollution	0.01	1.00	0.01
Total	2.47		36.34

Certainly the increasing in the rate of environmental taxes presented in Tables 43, 44 is a “black scenario” of electricity price development. We modelled the changing of electricity price (Fig. 56) due to increasing of CO_2 tax and the tax for oil shale ash disposal (other components of price were assumed constant). This modelling is very simple, but gives good overview of electricity price at the different tax rates.

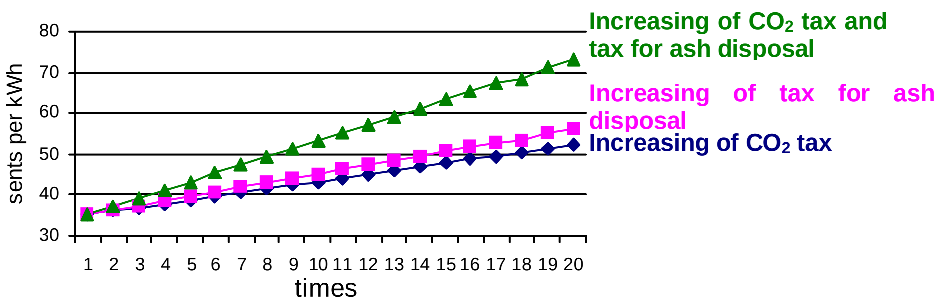


Figure 56. The trend of electricity price increases due to changing of CO_2 tax and tax for oil shale ash disposal from power plants.

Current fuel prices do not take into consideration external costs associated with the impact to the environment and human health. Adding external costs would increase the cost price for kWh oil shale electricity to the level of 2.4-3.0 EEK/kWh. External costs used (10-

15 €cents/kWh=1.5-2.25 EEK/kWh) were calculated, taking into account the data obtained in the EU project ExternE [http://externe.jrc.es/]. The external costs for production of electricity are in the case of using coal about 7 €cents/kWh, heavy fuel oil – 6 €cents/kWh, natural gas or biomass – 2.0 €cents/kWh, hydro energy – 0.4 €cents/kWh, and wind energy – 0.2 €cents/kWh.

External costs calculated by the methodology of ExternE take into account only damage to human health and do not consider damages to territories and deterioration of ecosystems, which should be added to the list. In the case of oil shale mining, the cost of maintaining the groundwater monitoring system, necessary irrigation systems, as well as possible expenditures for the development of a new regional water distribution system due to the pollution of the groundwater system should be added also.

According to the data of Eurostat, taking into account that the electricity price in Estonia is about 60% (90% using Purchasing Power standard) of the EU average (Fig. 1- 4 in Appendix VIII). How will the price of electricity change after the harmonisation of ("balanced") environmental taxes with taxes of the countries of European Union – this is a vital question for the future of Estonian energy sector.

4.1.2. Cost of shale oil

As for electricity and heat production, the data presented in this chapter do not give the full price structure of shale oil and are based on the methodology of the estimation of cost price suggested by Reinsalu [Reinsalu, 2000; Reinsalu E., 1984].

The shale oil factory price is estimated taking into account raw material (oil shale) price, share of raw material price in shale oil price (about 70% of the total expenses of shale oil production), and technological yield of shale oil (3).

$$\text{Shale\_oil\_factory\_price} = \frac{\text{raw\_materials\_price}}{\text{oil\_yield} \times \text{expenses\_per\_raw\_materials}} \qquad (3)$$

According to the estimation with this equation, the shale oil factory price was 11$ per barrel in 2002, other expenses should be added to this price to calculate the sale price of shale oil.

The cost price of shale oil was modelled by Reinsalu for all oil shale deposit (Fig. 57). As it can be seen, the current shale oil prime price is 18$ per barrel, however, with moving the mining tosouth would increase the price significantly.

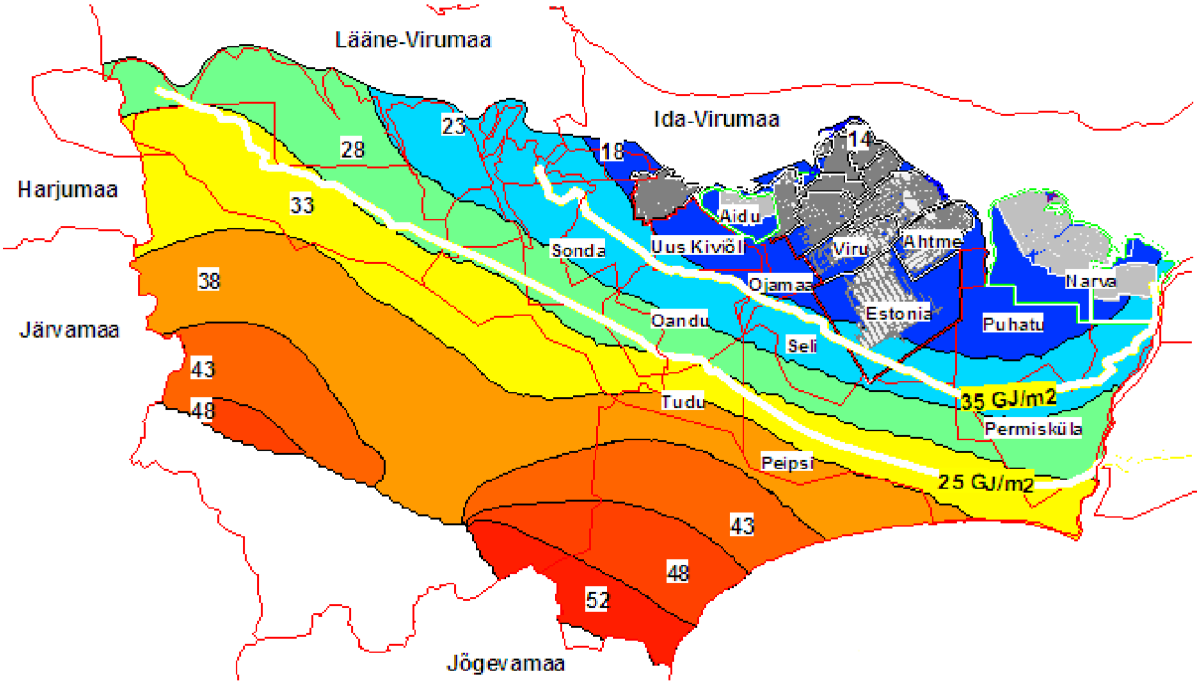


Figure 57. Shale oil cost, USD/barrel [Valgma I., Estonian oil shale resources calculated…].

The average selling price of shale oil was 1,989 EEK per tonne or 21 $ per barrel in 2003. However, in this context it is important to note that the chemical industry was buying oil shale at a lower price than the power plants (102EEK against 122EEK).

The shale oil is mostly being exported - about 50% of the total produced shale oil (Fig. 58). Taking into account the differences between selling price and prime price of oil shale, the total profit of the chemical industry should have been about 1,500 thousand EEK in 2002, where 850 thousand EEK was profit from the sale of shale oil on foreign markets.

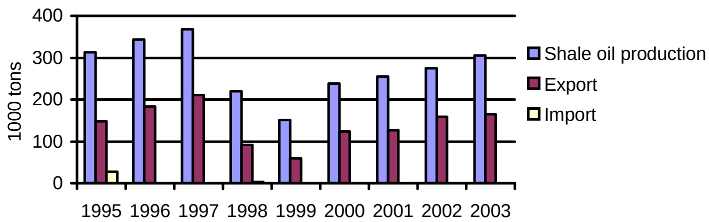


Figure 58. The dynamics of shale oil production, export and import [www.stat.ee].

4.2. Vertical monopoly of oil shale industry

The total sum of intra-group barter(?) deals was 8,586,909 thousand EEK in 2002/2003. The data in Table 45 need a separate detailed analysis.

Table 45. Revenues of AS Eesti Energia in 2002/2003 financial year, 1000 EEK [Eesti Energia Annual…, 2003]

	Oil shale mining	Production of electricity and heat	Transmission of electricity	Distribution of electricity	Sales and customer service	Support services
Revenue						
Net sales						
External revenue	258,042	863,020	63,171	22,769	4,366,036	148,329
incl. Estonia	257,787	795,379	35,339	20,657	4,007,395	101,436
incl. export	255	67,641	27,832	2,112	358,641	46,893
Intra-group revenue	1,483,781	3,217,343	799,609	1,965,363	697,426	423,378
% from the total revenue	85%[1)]	78%	92%	99%	14%	73%
Total	**1,741,823**	**4,080,363**	**862,780**	**1,988,132**	**5,063,462**	**571,707**
Other revenue	9,043	23,154	1,753	1,727	9,738	10,205
Total revenue	**1,750,866**	**4,103,517**	**864,533**	**1,989,859**	**5,073,200**	**581,912**

[1)]Oil shale selling to Power Plants

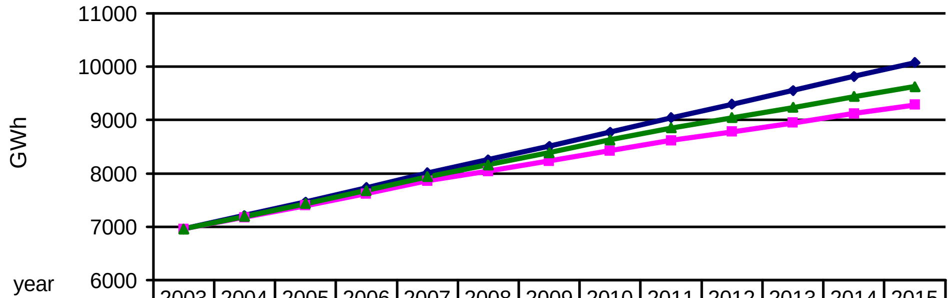
5. Possible future developments of the Estonia's energy sector – government policy

This chapter is based totally on official documents of the Estonian government, in which future scenarios of energy sector development are considered [Estonian electricity sector development plan 2005 – 2015; Long-term fuel and energy sector development until 2015].

The goals in the area of environmentally friendly development of the energy sector have been set as follows:

- 2005 – after joining EU Estonia takes obligation to use "Best Available Technology" (Circulating Fluidised Bed Technology in the case of oil shale industry);
- 2008 – all old TP-17 boilers should be closed, obligation taken on joining EU;
- 2009 – deadline to renew ash removal technology of oil shale power plants, obligation taken on joining EU;
- 2009 – requirement to open 35% of Estonian electricity market;
- 2010 – ends transition period for Ahtme Power Plant;
- 2010 – a promise(?) to transfer two additional blocks in Narva power stations to Circulating Fluidised Bed Technology;
- 2010 – requirement to increase electricity generation from renewable sources to 5.1% of the gross consumption;
- 2012 – requirement to reduce SO_2 emission to the level of 25,000 thousand tonnes;
- 2013 – requirement to open 70% of Estonian electricity market;
- 2015 – end of transition period for current blocks of Kohtla-Järve Power Stations and Narva Power Stations;
- 2015 – a promise(?) to transfer three additional blocks in Narva power stations to Circulating Fluidised Bed Technology;
- 2015 – requirement to increase electricity generation from renewable resources to 7.5% of the gross consumption;
- 2016 – old pulverized firing boilers are not allowed to be used for electricity generation according to the Directive of large combustion plants (Directive 2001/80/EC);
- 2020 – requirement that by 2020 electricity produced in combined heat and power production stations reaches 20 per cent of the gross consumption.

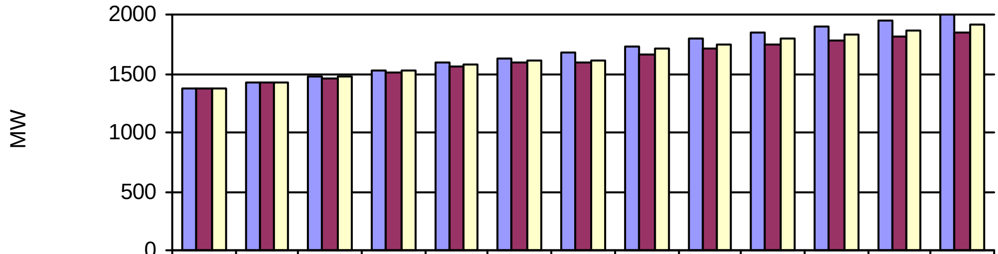
The strategic goal of the Estonian Electricity Sector Development Plan is "to satisfy the market condition of optimal functioning of Estonian National electricity system and its development, and the satisfaction of consumers' requirements in a long-term perspective, with as low as possible a price" [Estonian electricity sector…, 2004].



year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
High growth	6959	7209	7465	7731	8008	8255	8510	8773	9046	9297	9556	9823	1007
Low growth	6959	7174	7393	7621	7858	8042	8230	8425	8615	8781	8950	9124	9285
Moderate growth	6959	7193	7431	7679	7937	8160	8390	8627	8851	9043	9239	9441	9629

Figure 59. Prognosis of Estonian domestic electricity consumption [Tammoja H., 2004a].

Estonian electricity consumption to 2015 had been modeled on the initiative of the Ministry of Economic Affairs and Communications (Fig. 59) [Tammoja H., 2004a]. Economic parameters (GDP increase rate), social parameters (population growth rate, electricity consumption per capita) and technological parameters (technological development of energy sector, losses of electricity in network) were taken into account in modeling. According to electricity consumption predicted, the peak burden prognosis had also been modeled (Fig. 60).



year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
High growth	1378	1428	1478	1531	1586	1635	1685	1737	1791	1841	1892	1945	1995
Low growth	1378	1421	1464	1509	1556	1592	1592	1668	1706	1739	1772	1807	1839
Moderate growth	1378	1424	1472	1521	1572	1616	1616	1708	1753	1791	1830	1869	1907

Figure 60. The forecast of peak burden of power consumption [Tammoja H., 2004a].

As seen from Fig. 59 and Fig. 60, electricity consumption is expected to grow 2–3.75% annually, Estonian power capacity will reach 1,907 MW (moderate growth) by 2015.

Possible energy resources for Estonia were analyzed by researchers from Tallinn University of Technology on the the initiative of the Ministry of Economic Affairs and Communications [Tammoja H., 2004b]. It is expected that the consumption of **natural gas** is to be doubled in Europe by 2010 and the gas consumption will increase also in Estonia. The transportation capacity of pipelines and border metering stations is 8 – 10 mln m^3 in a twenty-four hour period. The maximum of 5–5.5 mln m^3 in a twenty-four hour period is used in winter months (at -20^{0}C). If the combustion of natural gas will increase then it is considered necessary that the state should have additional guarantees for the security of supply of natural gas, as 100% of natural gas is imported from Russia. The price of gas in the long-term perspective is an important parameter, and should be taken into account. Estonia may increase the share of natural gas consumption without concerns of security of supply if it participates in the development of underground gas storage facilities in Latvia through purchases of stocks of the facilities. The risk in the gas supply would be further reduced if Estonia takes part in the construction of a pipeline from Russia to Europe and the Estonian system of supply is connected to this pipeline. The possible implementation of this project will take 10 years. In addition, the connection of the gas networks of Estonia and Finland (Helsinki) has been discussed [Long-term fuel...].

Biofuel includes wood, straw, manure and waste. Estonia's current firewood reserve is estimated at 3,240 thousand m^3; by 2032 the reserve may decrease to 960 thousand m^3 because the forest age structure is changing. The firewood price is growing and will continue to grow; the current firewood price is 150 EEK/MWh [Estonian electricity sector…, 2004]. About 1.6 TWh of energy was generated from firewood in 2001. The energy resource from agricultural waste (straw, manure, including biogas) is estimated at 1 TWh of primary energy. The predictable generation of biogas will be about 0.15 TWh of electricity in 2030 [Long-term fuel...].

Peat is a local Estonian fuel. The peat reserve that can be used is estimated at 775 million tonnes. Annual energy generation from peat is 5.3 TWh [Paist, Kask et al., 2002].

The average **wind** speed is 7-9 km/s in Estonia. The islands of West Estonia, the coastal area of North-West Estonia and South-West Estonia are the most suitable areas for installation of wind power stations (Table 46). It is possible to install wind power generators with a capacity of 90 – 100 MW, but this would result in the deterioration of the operating quality of the power system. The maximum installation capacity of wind turbines without any negative effects is 30-50 MW. The expansion of the capacity of wind turbines requires sound investments into power networks and power stations [Long-term fuel...].

The available resource for the small-scale **hydropower** industry is estimated at ≈ 40 MW; the Narva river hydropower capacity is not taken into account, because it belongs to Russia.

Table 46. The structure of renewable sources in the gross electricity production 2005 – 2015 [Estonian electricity sector…, 2004]

	2005	2010	2015
Wind	1.0% (~ 20MW)	2.2% (~ 80MW)	4% (~ 160MW)
Biofuels	0.2%	2.5% (~ 30MW)	3% (~ 40MW)
Other	0.3%	0.4%	0.5%

Another important aspect in the Estonian power generation system is the development of the capacity of combined heat and power generation. According to a European requirement, Estonia should ensure that electricity produced in the combined heat and power stations forms 20% of the gross consumption. Current Estonian electricity ouput from combined power plants is 13% (the data of 2002 [Tammoja H., et al., 2004b]). The potential of electricity and heat production is estimated at 152.2 MW_{el} (electric capacity) and 459 MW_h (heat capacity) [Tammoja H., et al., 2004b].

Currently three scenarios for the Estonian power generation sector are considered officially by the Estonian government.

Scenario No. 1

The renovation of Narva Power Stations according to the investment plant of AS Eesti Energia (Tables 1, 2 Appendix IX):

§ from 2005 power unit 1 and 2 (2*215 MW) with Circulating Fluidized Bed (CFB) Technology are in exploitation.
§ 3rd power unit will be renovated (to 300 MW).
§ 4th power unit will be renovated (215 MW).
§ 5th power unit will be renovated (215 MW).
§ 6th power unit will be renovated (215 MW).

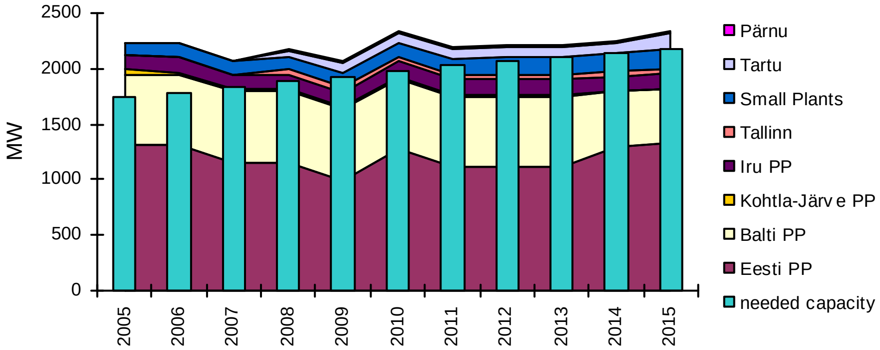


Figure 61. The forecast of required capacity and available capacity of power plants according to the first scenario, MW [Tammoja H, 2004b].

As can be seen, the electricity generation according to this scenario is fully based on oil shale. The strong side of this scenario is local fuel consumption that makes the state independent of fuels import and gives full control of the electricity price [Estonian electricity sector…, 2004].

However, taking into account all the negative effects of the oil shale industry on the environment, this scenario can not be attractive. This means that depletion and pollution of natural resources will continue as at present.

Scenario No. 2

No more oil shale power units will be renovated in the future. From 2007, three new gas power units will be built and they will be operated together with the existing two renovated oil shale power units.

§ from 2005 power unit 1 and 2 (2*215 MW) with Circulating Fluidized Bed (CFB) Technology are in exploitation.
§ 1st gas power unit will be built (300 MW).
§ 2nd gas power unit will be built (300 MW).
§ 3rd gas power unit will be built (300 MW).

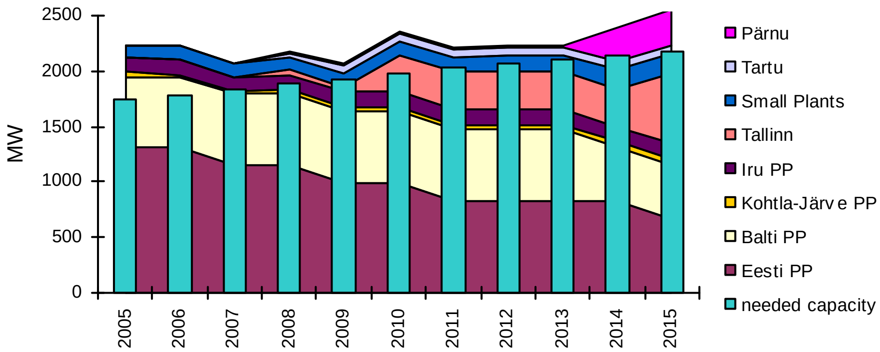


Figure 62. The forecast of required capacity and available capacity of power plants according to the second scenario, MW [Tammoja H, 2004b].

The weak side of this scenario is 100% dependence on gas import and the impossibility of controlling the electricity price.

Scenario No. 3

Two more oil shale power units will be renovated and a new gas power unit will be built.

§ from 2005 power unit 1 and 2 (2*215 MW) with Circulating Fluidized Bed (CFB) Technology are in exploitation.
§ 3rd oil shale power unit will be renovated (to 300 MW).
§ 4th oil shale power unit will be renovated (215 MW).
§ New gas power unit (station) will be built (300 MW).

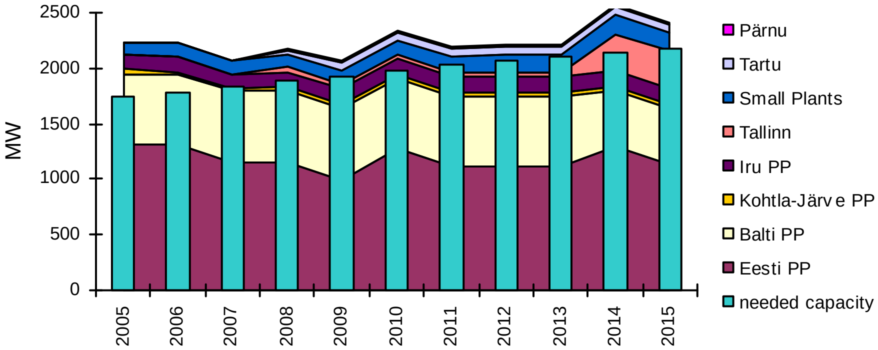


Figure 63. The forecast of required capacity and available capacity of power plants according to the third scenario, MW [Tammoja H, 2004b].

This scenario is considered as the most attractive and the most appropriate for the Estonian energy sector [Estonian electricity sector…, 2004] and according to it, only(?) 68.3% of electricity would be generated from oil shale (Fig. 64).

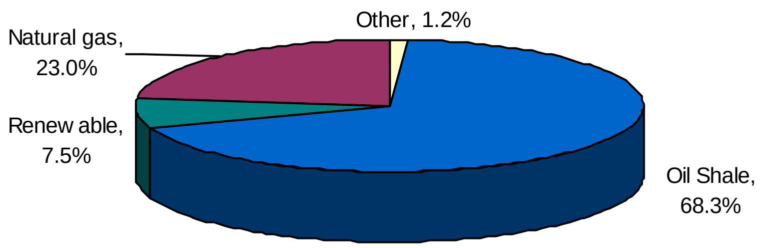


Figure 64. The predicted structure of electricity production in 2015 [Estonian electricity sector…, 2004]

It means that unsustainable water use - water pumping of 9–26 m^3 per tonne of oil shale during mining, 100 m^3 of cooling water per tonne of oil shale used at power plants, and emission of CO_2 - 1 tonne/MWh will be continued, and Estonia will continue to be one of the highest emitters of greenhouse gases per GDP in the world and EU.

6. Conclusions

1. Life Cycle Analysis of the oil shale industry in Estonia was carried out and it was shown that the overall efficiency of the power generation from oil shale is 14%, which could increase with the introduction of Fluidized Bed Combustion Technology maximally to 17%. Overall efficiency of heat generation from oil shale in the currently operating power plants is 34%.

2. The low efficiency of power generation leads to the high emission of CO_2 per capita (12-14 tonnes of CO_2 per capita annually). However, thanks to the fact that 1990 was chosen as the base year in the Kyoto Protocol, Estonia as an Annex B country met its obligations to decrease CO_2 emissions by 8% even before the Protocol was signed. 21 million tonnes of oil shale was extracted and used in 1990 mainly for power generation, whereas by 1994 the extraction decreased to 10-12 million tonnes per year. 1 tonne of CO_2 is emitted per 1 tonne of oil shale burned.

3. Overall energy intensity of the Estonian economy is high – 1,156 kgoe/1000€ in 2003. It is two times higher than the European average, taking into account also such states as Bulgaria and Romania. It is about 10 times higher than the intensity of the economy of Denmark.

4. A detailed analysis of the cost price structure of oil shale and electricity generated from oil shale showed that resource and environmental taxes comprise only 5% and 6% of the total cost price respectively. This is explained by the fact that most of the resource and environmental taxes for the oil shale industry are lower, in some cases very remarkably lower, than for the other industries in Estonia, not to mention neighboring countries. For example CO_2 tax in Estonia is currently 11.5 EEK/tonne of CO_2 which is €0.73 per tonne of CO_2. In addition, power stations are the biggest owners of CO_2 credits – 52 million tonnes of CO_2 credits for 2005-2007 .

5. Based on the energy rating of oil shale seams, the economic reserve of oil shale in 2002 was estimated at 1,488 million tonnes (29% of the total reserves) - 18,478 PJ. Estonian subeconomic reserves were 3,511 million tonnes (71% of the total). Taking into account that about 10-15 million tonnes of oil shale is extracted annually, it could be estimated that the reserves in the operating mining are sufficient for use at the current rate for the next 20 - 30 years.

6. The environmental impact of the oil shale industry is huge, and it is determined by the chemical composition of kukersite (Estonian oil shale), and the peculiarities of the geological structure of the Estonia deposit of oil shale:
    a. The content of kerogen (organic matter of kukersite) varies from 10 to 65%, being 40% in oil shale of good quality.
    b. The oil shale bed is comparatively thin – 3.5 tonnes of oil shale, 30-35 GJ, can be extracted on average from $1m^2$.
    c. 9-26 tonnes of water must be pumped out from the underground mines and open pits per each tonne of oil shale mined.
    d. 100 m^3 of cooling water is used at power plants per tonne of oil shale burned.

7. Since 1918 over 900 million tonnes of oil shale has been mined out in Estonia; that is 1.6 billion tonnes with losses and written-off resources.
    a. 600 million tonnes of commercial oil shale has been removed from beneath the ground in Ida-Viru County. It has left behind a cave of more than 400 million m^3, which has been partially flooded during the first years after the mines were abandoned. It has been estimated that there is about 160 million tonnes of (polluted) groundwater in the abandoned caves, which are spread over almost 300 km^2.
    b. 350 million tonnes of oil shale has been extracted in opencast mines. They cover 120 km^2.

8. A detailed analysis of the regional groundwater balance was carried out and it was shown that the use of groundwater bodies is not sustainable The quantitative status of the Ordovician groundwater body in the Ida-Viru oil shale basin as well as the quantitative statuses of the Cambrian-Vendian Voronka and Gdov groundwater bodies are bad in Northeast Estonia. The allowed maximum pumping rates (proved reserves) are overestimated for the Quaternarian Vasavere groundwater body and especially for the Cambrian-Vendian Voronka and Gdov groundwater bodies. These findings are in contrast with the position of the research carried out by the Ministry of Environment of Estonia [Viru-Peipsi Catchment…2004], in which the statuses of the same Voronka and Gdov groundwater bodies were evaluated as good.

9. Oil shale power stations use 1,085,596 thousand m^3 of cooling water (2002).

10. 0.5 - 0.6 tonnes of solid wastes with organic matter content 6-12% per tonne of oil shale used commercially is generated in the oil shale enrichment plants. The wastes have been deposited in 34 different places, which contain 165 million tonnes of solid wastes and the heaps cover 337 ha. Due to the content of organic matter, these waste heaps occasionally self-ignite. 27% of heaps have been recorded to self-ignite up to now. Leachates of high organic pollution are formed as the result of burning of the heaps.

11. 0.4 – 0.5 tonnes of ashes is generated in the power stations per tonne of oil shale used. The oil shale ashes are classified as hazardous wastes by Decision 2000/532/EC. Ashes are deposited next to the power stations using hydrotransport. 283 million tonnes is deposited in Narva Power Plants; the wastes cover 2002 ha together with the settling ponds.

12. The pH of leachates from the ashes is 12.4-12.7. The leachate contains high levels of Al, Si, Ga, Na, Li, Cs, Rb, Co, Mn, V and Zn.

13. 2,283 thousand tonnes of oil shale (17%) was used for the production of shale oil in 2002. Oil shale for the production of shale oil is supplied to the chemical plant below the market price. Taking into account also the increase in oil prices, production of shale oil has become economically very profitable.

14. 2.9 tonnes of solid wastes and 67 kg of fuses are generated per tonne of shale oil using Kiviter process. The wastes of shale oil production are extremely hazardous to the environment. The wastes are deposited on 248 ha, where 96 million tonnes of hazardous wastes have been accumulated.

15. 0.7-0.88 million tonnes of leachate is formed annually and is discharged without treatment into Purtse River from the semi-coke landfills of Viru Keemia Grupp using the Kiviter process for the production of shale oil. The pH of the leachate varies from 8.47 to 12.54; the concentration of Total Organic Carbon (TOC) varies from 12 to 14%, which already do not meet the environmental requirements of Directive 2003/33/EC, Item 2.4.2.

16. Post-technological processes:
    a. Unstable or quasistable land exists on the territory of underground mines – altogether on 280 km^2 – there is a real danger of abrupt changes of relief
    b. A cave of 400million m^3 over 300 km^2 has been formed; currently it is filled with 160 million m^3 of polluted water, which will be increased in the result of further mining after exhausted mines are abandoned. As the result of long-term leaching of substances from supporting pillars left in the mines, the risk of powerful hydraulic shocks due to the destruction of the pillars will increase.
    c. Caves of the mines together with the shafts form in fact a regional technogenic “karst” area. There are no investigations of the long-term environmental impact of this “karst” area on the regional water resources and bodies.
    d. Caves filled with polluted water significantly increase the spreading of pollution to the regional water bodies. The rapid movement of pollution is facilitated also by the fracturing of the aquitards with the collapse of the mine ceilings, by thousands of explosions used in the mining, and by changes of the relief due to opencast mining.
    e. Solid wastes of mining, ash from the power plants, and wastes of chemical plants pose a very long-term threat to the soil and water resources in the region.

17. Analysis of the scenarios for the development of the energy sector of Estonia proposed by the Ministry of Economic Affairs and Communications has been carried out. It was noted that, almost exclusively, scenarios based on the further use of oil shale are considered. Alternatives (use of renewable energy resources, clean coal technologies, distributed generation, even the potential of CHP etc.) have not been analyzed seriously up to now.

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APPENDIXES

Appendix I

Table 1. Production of primary energy, PJ [www.stat.ee]

	1960	1970	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total	113.0	223.3	311.0	262. 7	223.6	148.8	164.2	162.0	136.1	124.6	132.4	132.0	140.3	160.0	152.0
oil-shale	100.3	203.6	296.4	250.5	209.6	122.4	133.9	130.6	112.8	97.8	108.3	106.2	111.1	132.1	124.1
peat	5.2	9.9	9.2	4.3	6.2	5.6	6.5	5.4	1.5	5.4	3.3	3.4	6.4	3.5	2.7
firewood	7.5	9.9	5.3	7.8	7.9	20.7	23.7	25.9	21.6	21.2	20.6	22.3	22.6	24.2	25.0
other fuels	0.0	0.0	0.0	0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
hydro- and wind energy	0.1	0.01	0.0	0	0.0	0.009	0.010	0.008	0.012	0.016	0.017	0.021	0.028	0.1	0.1

Appendix II

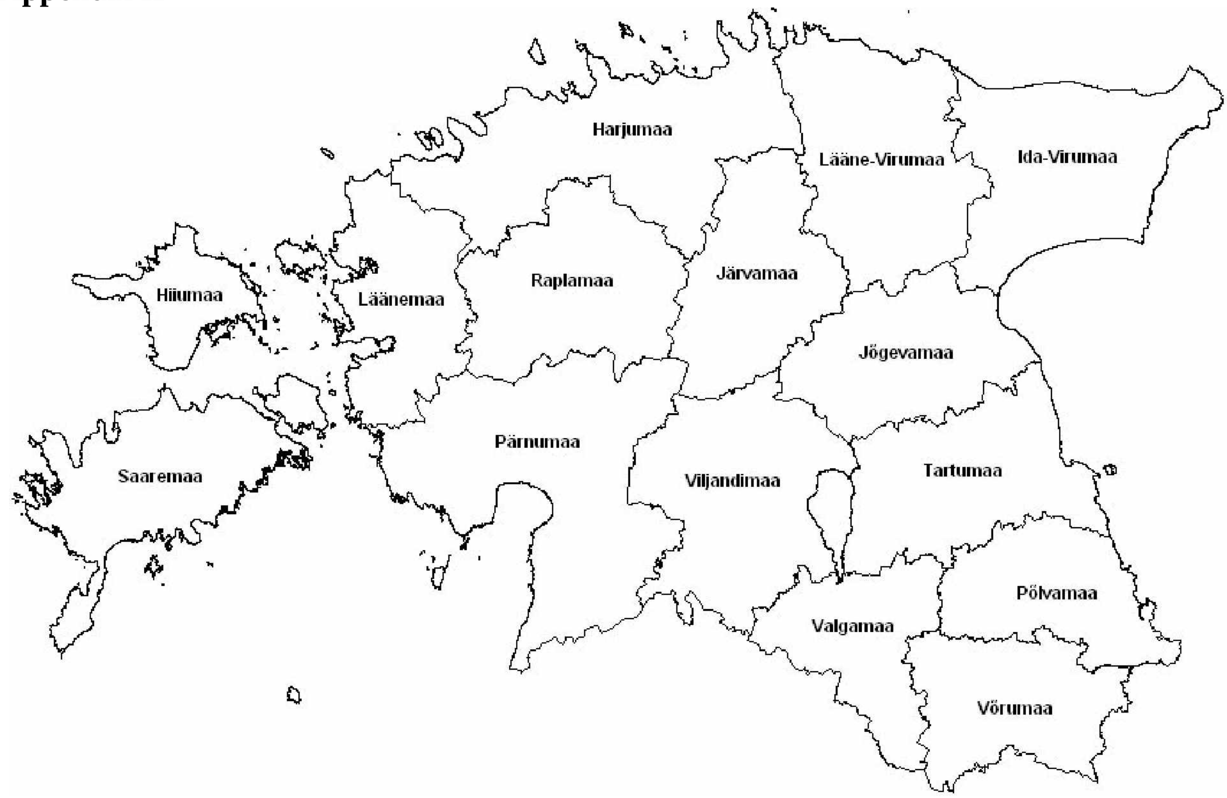


Figure 1. The map of Estonian counties.

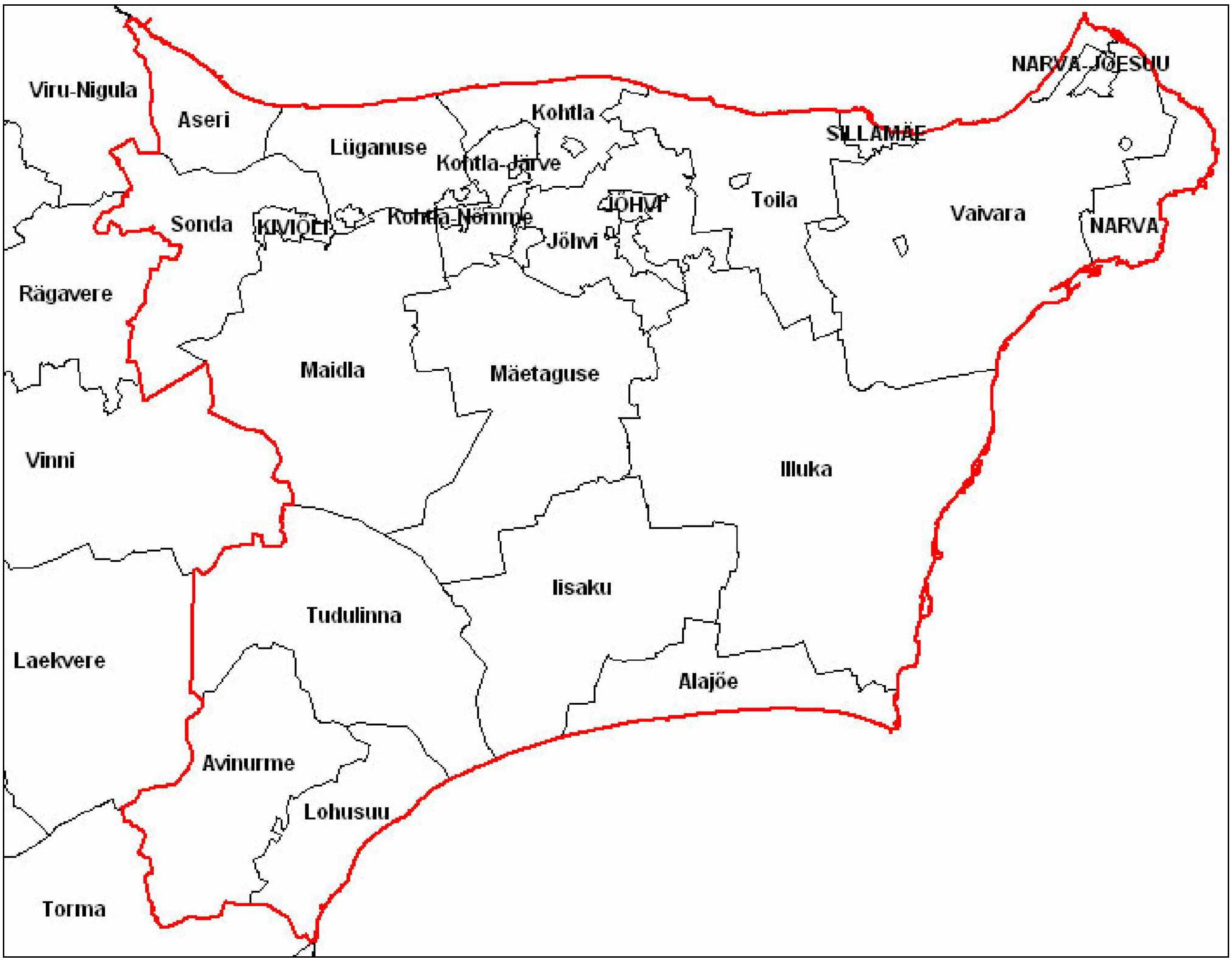


Figure 2. The map of rural municipalities of Ida-Viru county.

Appendix III

Table 1. Oil shale reserves by fields on 1998 [Kattai V., et al., 2000]

	In limits of deposit			In limits of mining field		Oil shale reserve, mln t	
		including			including		including
	Area, km^2	Mined out	Without reserve	Area, km^2	Nature conservation area	Total reserve	in nature conservation areas
		Eastern part					
Narva	62.2	24.2		38	0	105.7	
Permisküla	185.3	0		185.3	95.4	518.4	267.8
Puhatu	154.4	0		154.4	71.6	474.8	215
Sirgala	130.9	68.3		62.6	9.4	203.5	31.2
Total	**532.8**	**92.5**		**440.3**	**176.4**	**1302.4**	**514**
		Central part					
Ahtme	50.9	32.7		18.2	0.9	57	2.6
Aidu	34.2	19		15.2	0	54.7	0
Estonia	185.8	49.1		136.7	11.3	464.6	38
Kohtla	26	18.9		7.1	0	24.6	0
Ojamaa	34.6	0		34.6	0.6	118.4	2.2
Seli	86.7	0		86.7	9.9	248.4	28.3
Sompa	33.8	25.2		8.6	0	28.5	0
Tammiku	44.4	26.9		17.5	0	55.1	0
Viru	41.9	21.1		20.8	0	68.5	0
Liquidated	110	110		0	0	0	0
Total	**648.3**	**302.9**		**345.4**	**22.7**	**1119.8**	**71.1**
		Western part					
Kabala	41.9	0		41.9	41.9	116.3	116.3
Kohala	87.5	1.3		86.2	77.8	280.1	254.3
Oandu	152.5	0	26.6	125.9	8.5	337.5	22.1
Pada	37.3	1.3	5.7	30.3	5.6	91.9	17.2
Põhja-Kiviõli	14.7	0		14.7	0	40.3	0
Sonda	177.1	0		177.1	24	507.9	69.6
Ujaste	26.6	0	1	25.6	5.7	79.1	18.5
Uus-Kiviõli	62.5	0		62.5	0	209.5	0
Liquidated	28.5	28.5		0	0	0	0
Total	**628.6**	**31.1**	**33.3**	**564.2**	**163.5**	**1662.6**	**498**
		North-western part					
Halja	165.4	0		165.4	13.4	460.6	38.8
Kõnnu	114.3	0	114.3	0	0	0	0
Rakvere	310.4	0	310.4	0	0	0	0
Total	**590.1**	**0**	**424.7**	**165.4**	**13.4**	**460.6**	**38.8**
		Southern part					
Peipsi	262.7	0	182.9	79.8	0	491.1	0
Tudu	209.8	0	209.8	0	0	0	0
Total	**472.5**	**0**	**392.7**	**79.8**	**0**	**491.1**	**0**
Total reserves	**2872.3**	**426.5**	**850.7**	**1595.1**	**376**	**5036.5**	**1121.9**
In Ida-Viru county	**1955.9**				**3749.9**		
In Lääne-Viru county	**945.6**				**1286.6**		
In Harju county	**71**				**0**		

Table 2. Oil shale reserves by fields, GJ/m^2 [Kattai V., et al., 2000]

	Energy rating of commercial steam, GJ/m²	Oil shale reserve, mln t		Steam depth, m
	45 40 35 30 25 20	Measured Ta+Ra	Marginal Tp+Rp	
KAEVEVÄLI	Ahtme	27+0	27+3	40-50
	Tammiku	11+7	32+4	3-40
	Sirgala	83+0	98+21	3-35
	Kohtla	10+0	13+0	3-25
	Sompa	26+0	2+0	25-40
	Viru	41+16	2+9	35-50
	Aidu	46+2	1+5	3-25
	Estonia	280+116	51+15	50-70
	Narva	63+0	41+0	5-35
	Total	587+141	267+57	
UURINGUVÄLI	Ojamaa	59+38	2+20	25…50
	Puhatu	139+32	27+276	35…80
	Uus-Kiviõli	208+0	2+0	15…50
	P-Kiviõli*	0+31	0+9	2…20
	Uljaste*	0+35	0+44	3…20
	Permisküla	18+0	371+130	30…90
	Seli	56+0	192+0	45…70
	Sonda	88+15	334+71	20-50
	Oandu	0+0	192+146	30…80
	Pada*	0+0	0+92	3…25
	Kohala*	6+0	0+274	3…45
	Kabala	0+0	108+8	25…55
	Haljala	51+11	266+132	3…40
	Peipsi	0+0	0+492	50…80
	Rakvere	0+0	0+0	20..100
	Tudu	0+0	0+0	50..100
	Kõnnu	0+0	0+0	5…60
	Total	625+161	1494+1694	
	All total (5,0 mld t)	1212+302 1514	1761+1751 3512	

*the data need more accurate definition

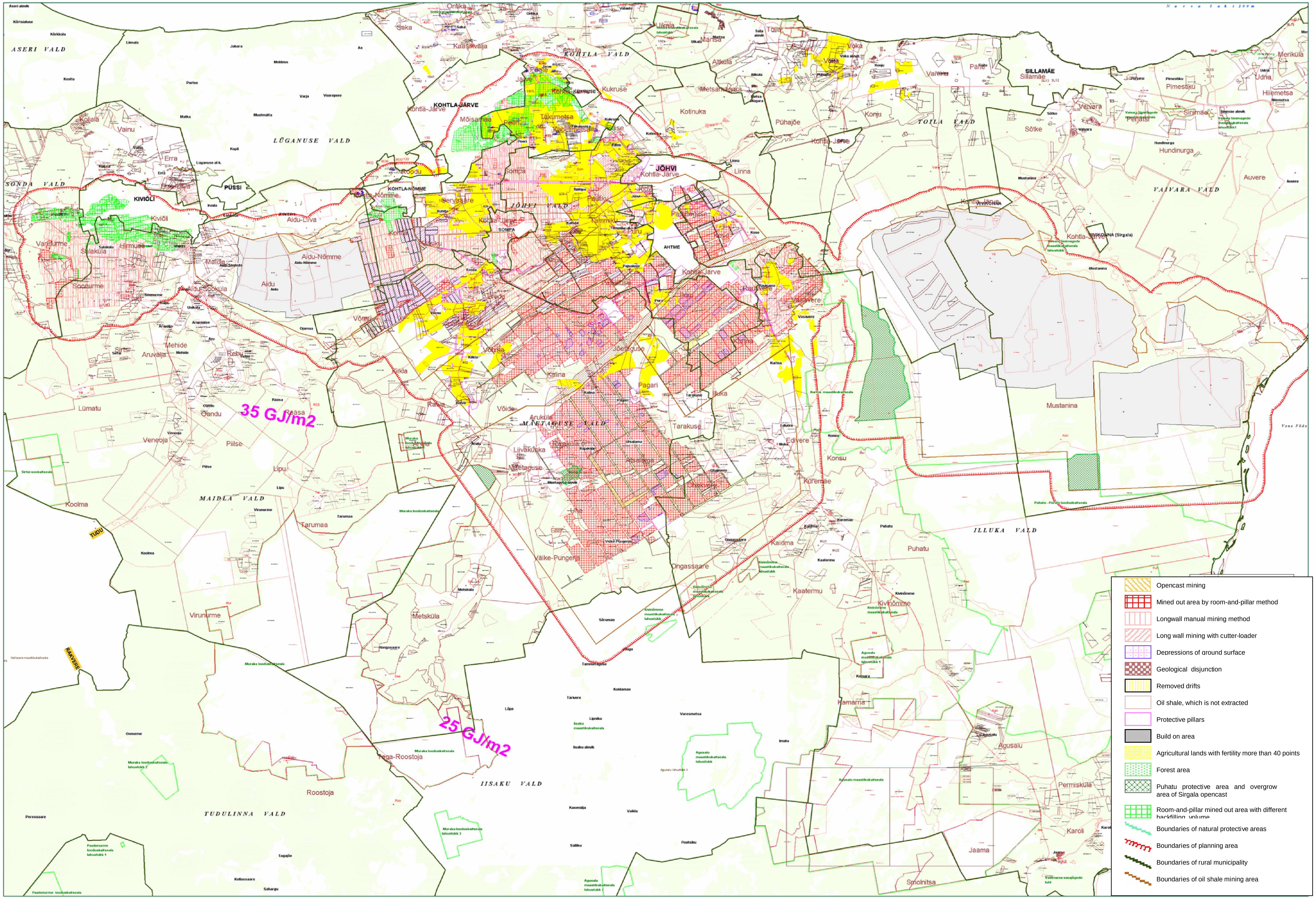


Figure 1. Mined out land by rural municipalities [Ida-virumaa maavalutsus..., 2001].

Appendix V

Additional calculations for the estimation of efficiency of electricity generation

The calculation of weighted average efficiency of electricity generation:

	Electricity output, GWh	Efficiency of Plant
Eesti PP	1,689.28	29%
Balti PP	5,254.99	28.2%
Kohtla-Järve CHP	16.976	11%
Ahtme CHP	34.315	8%
Total	6,995.561	

$$weighted\_average = \frac{1689.28*0.29+5254.99*0.282+16.976*0.11+34.315*0.08}{6995.561} = 28.3\%$$

Electricity consumption by “AS Eesti Põlevkivi”:

$$= \frac{124{,}370\ \text{thousand EEK}}{790\text{EEK/MWh}} = 157.43\text{GWh}$$

124,370 thousand EEK is the cost of “AS Eesti Põlevkivi” electricity consumption [Appendixes of annual bookkeeping…].
790 EEK/MWh is electricity price for large consumers [Energy balance 2002].

Additional calculations for the estimation of the efficiency of heat generation by power plants

The calculation of weighted average efficiency of heat generation:

	Heat output, GWh	Efficiency of Plant
Eesti PP	746.62	68%
Balti PP	107.92	68%[14]
Kohtla-Järve CHP	233.35	44%
Ahtme CHP	321.64	56%
Total	1,409.53	

$$\text{weighted\_average} = \frac{746.62 * 0.68 + 107.92 * 0.68 + 233.35 * 0.44 + 321.53 * 0.56}{1409.53} = 61\%$$

Heat consumption by “AS Eesti Põlevkivi”:

$$= \frac{3{,}717 \text{ thousand EEK}}{335 \text{ EEK/MWh}} = 11.095\text{GWh}$$

3,717 thousand EEK is the cost of “AS Eesti Põlevkivi” heat consumption [Appendixes of annual bookkeeping…].
335 EEK/MWh is heat price for large consumers [Energy balance 2002].

[14]Unfortunately we didn’t find a source with data on the efficiency of heat generation by Balti PP, and we used the parameter of Eesti PP

Appendix VI

Table 1. The reclamation areas of the territory spoiled by open mining (on 1999) [Kattai V., et al., 2000]

	Territory of open pits, km^2				
	Sirgala	Narva	Aidu	Kohtla	Total
All affected territory from the beginning of mining	68.1	25.2	21.1	3.8	118.3
Technically re-cultivated areas	62.3	21.6	16.3	3.3	103.5
Biologically re-cultivated areas	57.4	19.6	14.3	3.1	94.4
incl. Agricultural land			1.5	0.1	1.6

Table 2. The main parameters of landfills of oil shale wastes stored after enrichment [Sørlie J.-E., et al., 2004]

Location	Age	Height, m	Area, ha	Volume, 1000 m^3	Note
Kiviõli chemical factory	1949-1968	38	4.2	1,100	
Aidu quarry	1984-1999	14	0.87	1,400	
Kohtla-Nõmme mine	1952-1975	41	1.55	198	
Kohtla-Nõmme mine	1956-1968	40	2.95	576	
Kohtla-Nõmme mine	1968-...	26	9.35	1,431	
Sompa-4 mine	19...	40	4.58	990	
Sompa-4 mine	19...-1974	17	1.18	67	
Sompa mine	1964-1970	23	3.1	280	
Sompa mine	1968-1999	18	12.53	1,057	
Käva mine		0	0	0	
Kukruse mine	1945-1951	27	1.31	195	
Jõhvi No 2 mine		38	2.4	619	
Jõhvi No 2 mine		28	3.2	617	
Jõhvi No 2 mine		26	1.4	134	
Jõhvi No 2 mine		32	2.2	336	
Tammiku mine	1951-1965	12	1.5	63	
Tammiku mine	1975-1999	25	15.4	2,375	
Tammiku mine	1970-...	40	18	4,444	
Viru mine	1965-1980	16	8.1	945	
Viru mine	1967-1975	23	15	2,754	
Viru mine	1974-...	35	27.9	12,230	
Estonia kaevandus	1973-now	47	105.8	37,610	
Estonia kaevandus	1973-1978	19	13.5	1,964	
Ahtme mine	1946-...	55	5.55	1,320	
Ahtme mine	1965-2002	44	44.03	16,690	
Sompa-4 mine	19...	39	7.12	1,171	Self-burned
Sompa mine	1948-1964	42	4.27	344	Self-burned
Sompa mine	1949-1966	44	3.5	571	Self-burned
Sompa mine	1964-1967	31	1.6	188	Self-burned
Käva mine	1951-1959	61	5.22	982	Self-burned
Käva mine	1960-1972	13	1.03	71	Self-burned
Kukruse mine	1951-1967	41	4.76	756	Self-burned
Jõhvi No 2 mine		25	3	453	Self-burned
Jõhvi No 2 mine		41	1.3	267	Self-burned
Total			**337.4**	**94,198**	
where			**32**	**4,803**	**Self-burned**

Table 3. The volumes of stored semi-coke on landfills and its disposal area, according to the data of different sources [Sørlie J.-E., et al., 2004; Treatment plan…, 2005]

Location	Area, ha	Volume, 1000 m^3	Source
Kiviõli chemical factory	35	10,000	Sørlie J.-E., et al., 2004
Kiviõli chemical factory	47	11,300	Sørlie J.-E., et al., 2004
Kohtla-Järve chemical factory	93.4	62,067	Sørlie J.-E., et al., 2004
	Area, ha	Volume, 1000 tonnes	
Kiviõli chemical factory (abandoned)	35	6,312	Treatment plan…, 2005
Kiviõli chemical factory (abandoned)	10	684	Treatment plan…, 2005
Kiviõli chemical factory	35	13,000	Treatment plan…, 2005
Kohtla-Järve chemical factory	142	73,000	Treatment plan…, 2005

Table 4. The average contents of chemical elements in ash from Narva PPs and in semi-coke from Kohtla-Järve and Kiviõli [Sørlie J.-E., et al., 2004]

Element	Unit	Ash[1)]		Semi-coke[2)]	
		Total	Aqua region	Total	Aqua region
(1)	(2)	(3)	(4)	(5)	(6)
Al	%	3.965	2.565	2.635	1.228
Ca	%	26.88	22.74	19.68	18.654
Fe	%	3.1	2.69	2.81	2.492
K	%	2.965	2.23	1.8125	0.828
Mg	%	2.13	2.065	1.255	1.486
Mn	%	0.0465	0.04485		
Na	%	0.1095	0.059	0.06425	0.039
P	%	0.076	0.0645	0.044	0.046
S	%	2.765	1.445	1.515	1.048
Ti	%	0.2685	0.141	0.15775	0.042
Ag	ppb	102.5	45	84.75	27.8
As	ppm	26.05	16.3	8.325	5.32
Au	ppm	0.1	0.2	0.1	0.2
B	ppm		156.5		58.6
Ba	ppm	184.5	147.5	119.25	57.94
Be	ppm	1		1	
Bi	ppm	0.125	0.1	0.055	0.048
Cd	ppm	0.205	0.07	0.0875	0.02
Ce	ppm	37.135	24.55	26.765	16.56
Co	ppm	6	4.35	3.75	3.22
Cr	ppm	54	45.35	42.25	20.7
Cs	ppm	6.5		2.675	
Cu	ppm	10.76	7.855	7.2925	6.914
Dy	ppm	2.9	1.9	1.875	1.362
Er	ppm	1.4	1.06	0.925	0.708
Eu	ppm	0.7	0.465	0.5	0.364
Ga	ppm	11.985	9.05	6.57	4.32
Gd	ppm	3	2.35	2.25	1.684
Hf	ppm	2.4			1.404

(1)	(2)	(3)	(4)	(5)	(6)
Hg	ppb		22		14
Ho	ppm	0.4	0.345	0.325	0.242
La	ppm	26.5	15.75	18.25	10.38
Li	ppm	28.6			24.54
Lu	ppm	0.2	0.145	0.125	0.094
Mn	ppm			306.25	318.4
Mo	ppm	7.44	5.77	4.195	3.332
Nb	ppm	7.63		4.39	
Nd	ppm	17.95	11.61	13.1	8.102
Ni	ppm	26.55	21.15	21.975	17.36
Pb	ppm	69.9	48.655	41.5775	33.98
Pr	ppm	4.7	3.195	3.45	2.268
Rb	ppm	88.65		47.325	
Sb	ppm	5.25	0.385	0.245	0.124
Sc	ppm	6.1	5.3	4.225	3.56
Se	ppm		0.6		0.4
Sm	ppm	3.75	2.355	2.725	1.762
Sn	ppm	2.1			1.04
Sr	ppm	302.5	261.7	292.75	254.1
Ta	ppm		0.5		0.32
Tb	ppm	0.55	0.35	0.4	0.256
Te	ppm		0.025	0.0325	
Th	ppm	8.35	4.95	6.15	3.74
Tl	ppm		1.185		0.114
Tm	ppm	0.2	0.16	0.125	0.104
U	ppm	4	3.05	3.525	2.3
V	ppm	47.5	46.5	30.25	22.8
W	ppm	1.55	0.55	1.225	0.3
Y	ppm	16.45	11.235	11.9	8.262
Yb	ppm	1.75	1.1	1.1	0.722
Zn	ppm	73.2	55.2	26.925	22.08
Zr	ppm	76.75		40.45	

1) The average values are calculated on the basis of elements concentration in ash from filter and cyclone from Narva PPs

2) The average values were calculated on the basis of elements contents in fresh semi-coke wastes, less than 20 years old and more than 40 years old.

Table 5. The average contents of organic elements in semi-coke from Kiviõli and Kohtla-Järve [Sørlie J.-E., et al., 2004]

Unit	Element	Average content
(1)	(2)	(3)
PAH, mg/kg Dry Residue	Naphthalin	0.20
	Acenaphthen	0.05
	Acenaphthylen	0.10
	Fluoren	0.10
	Phenanthren	0.29
	Anthracen	0.13
	Fluoranthen	0.55
	Pyren	0.31

(1)	(2)	(3)
	Benzo[a]anthracen	0.18
	Chrysen	0.04
	Benzo[b]fluoranthen	0.15
	Benzo[k]fluoranthen	0.06
	Benzo[a]pyren	0.15
	Indeno(123-cd)pyren	0.05
	Dibenz[ah]anthracen	0.04
	Benzo[ghi]perylen	0.05
	Sum PAH	**2.22**
BTX, mg/kg Dry Residue	Benzol	0.02
	Toluol	0.04
	Ethylbenzol	0.01
	m+p-Xylol	0.05
	Styrol	0.01
	iso-Propylbenzol	0.01
	1,3,5-Trimethylbenzol	0.01
	Sum BTX	**0.13**
Phenols, mg/kg Dry Residue	Phenol	1.00
	Resorcin	0.05
	5-Methylresorcin	0.05
	2,5-Dimethylresorcin	0.05
	4-Ethylresorcin	0.05
	4-Methylphenol	1.26
	3,4-Dimethylphenol	0.12
	2,3-Dimethylphenol	0.56
	2,4-Dimethylphenol	0.75
	Sum phenols	**3.43**

The average value was calculated on the basis of organic compounds in different semi-coke wastes (fresh semi-coke, <20 old, >40 old) from Kiviõli and Kohtla-Järve landfills

Table 6. Allotment of areas influenced by underground mining of oil shale on 1999, km^2 and % [Reinsalu, E., et al., 2002]

Distribution of areas	Mining field, km^2	Mined areas		Un-mined areas		Subsidence areas, km^2		Stable territory, km^2				Caving areas, km^2	Unstable areas, km^2	
		km^2	%	km^2	%	Longwall faces, hand-mined	Room-and – pillar method, hand mined	Tectonic distur-bance	Rem-nants	Written off resource	Fell down areas	Longwall faces, mined by cutters	Drifts and area under question	Room-and-pillar method
Working mines														
Ahtme	43.3	34.7	80	8.9	20	6.3	0.1	0.1	1.5	0	1.64	0.5	9.1	17.2
Estonia	141.1	52.4	37	88.7	63	0	0	0	1	3	0.7	0	8.9	39.5
Kohtla	18.3	16.9	92	1.5	8	3.8	1.4	0.1	1.4	0	0	6.4	3.2	0.6
Sompa	33.6	26.7	79	7	21	12.7	0.1	0.3	1.2	2	0	3.5	5	1.9
Tammiku	40	39.6	99	0.4	1	4.4	0	2.4	8.7	0	0	2.7	9.6	11.8
Viru	41.7	28.1	67	13.6	33	0	0	3.4	1.6	0.3	0.76	0	7	15.7
Closed mines														
Mine No 2	12.3	12.3	100	0	0	6.8	0	0.1	1	0.7	0	0	2	1.7
Mine No 4	12.7	12.7	100	0	0	7.7	0	0	0.6	0	0	0.9	2.3	1.1
Kiviõli &Küttejõud	28.9	28.9	100	0	0	14.9	6.6	0	0	0	0	0	6	1.5
Kukruse	13.2	13.2	100	0	0	6.3	3.5	0.2	0.4	1.1	0	0	1.4	0.3
Käva	18	18	100	0	0	9.1	3.7	0	0.4	1.1	0	0	3	0.7
In total	**403**	**283**	**70**	**120**	**30**	**72**	**15**	**7**	**18**	**8**	**3**	**14**	**57.6**	**91.9**

Quasi-stable areas – mined using room and pillar method in mines Estonia, Viru, Ahtme - ~70 km^2 – liable to fell down in next decades

Appendix VII

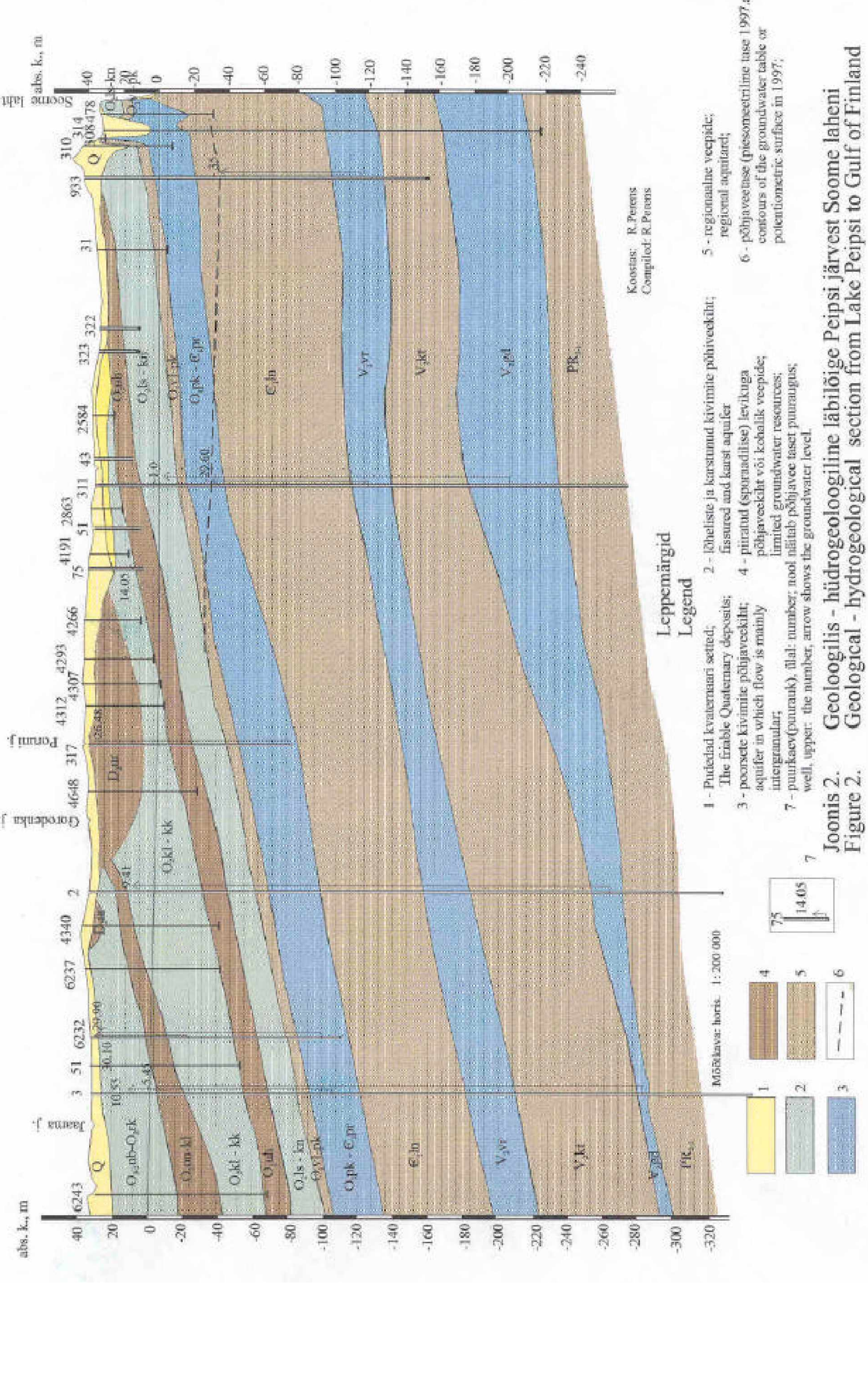
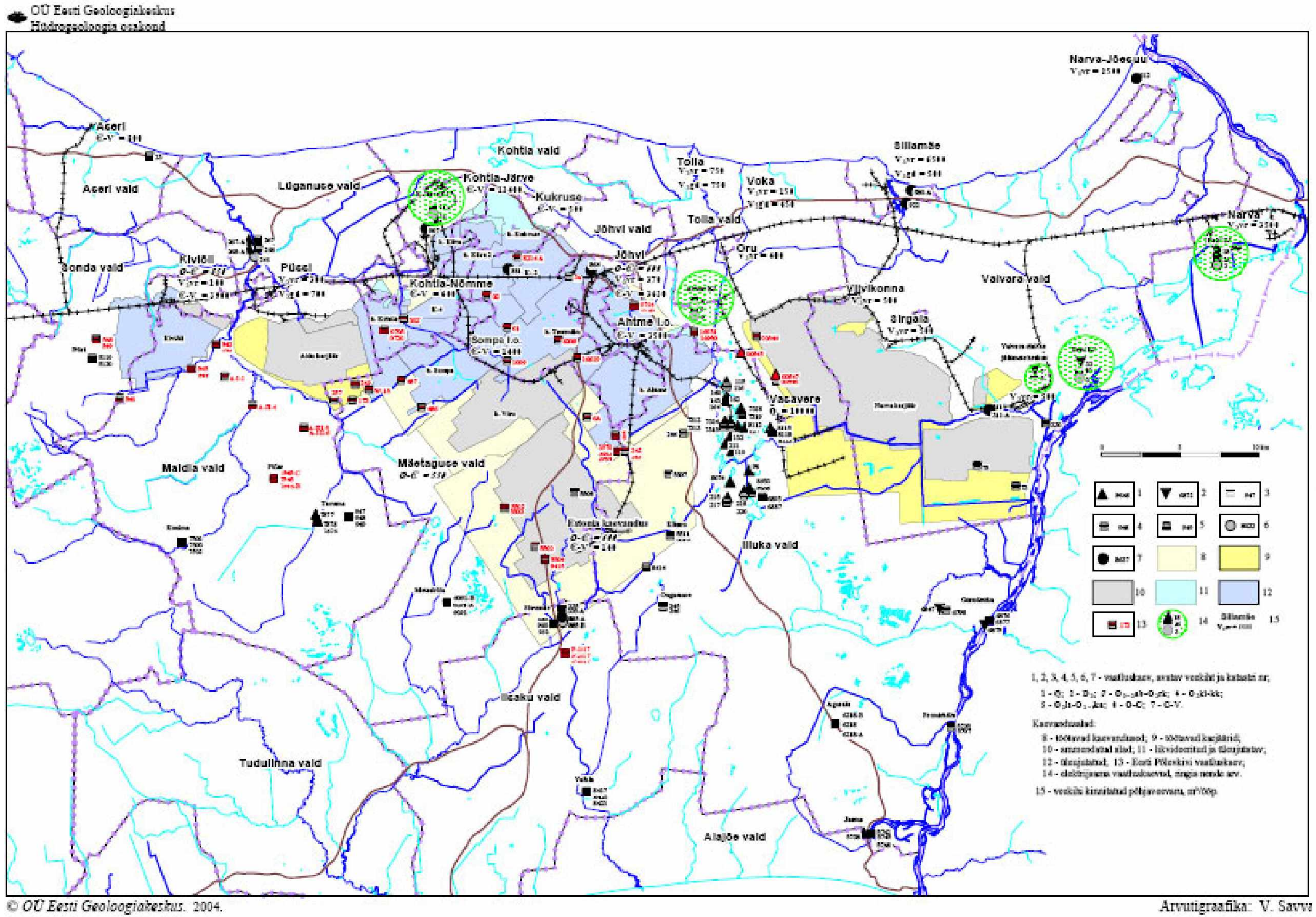


Figure 1. Geological-Hydrological section from Lake Peipsi to Gulf of Finland [Perens R., et al., 2001].



Joonis 1.2.28. Seirepuurkaevude asukohaskeem Ida-Viru seirepiirkonnas.

Figure 2. Location of groundwater wells [Perens R., et al., 2005].

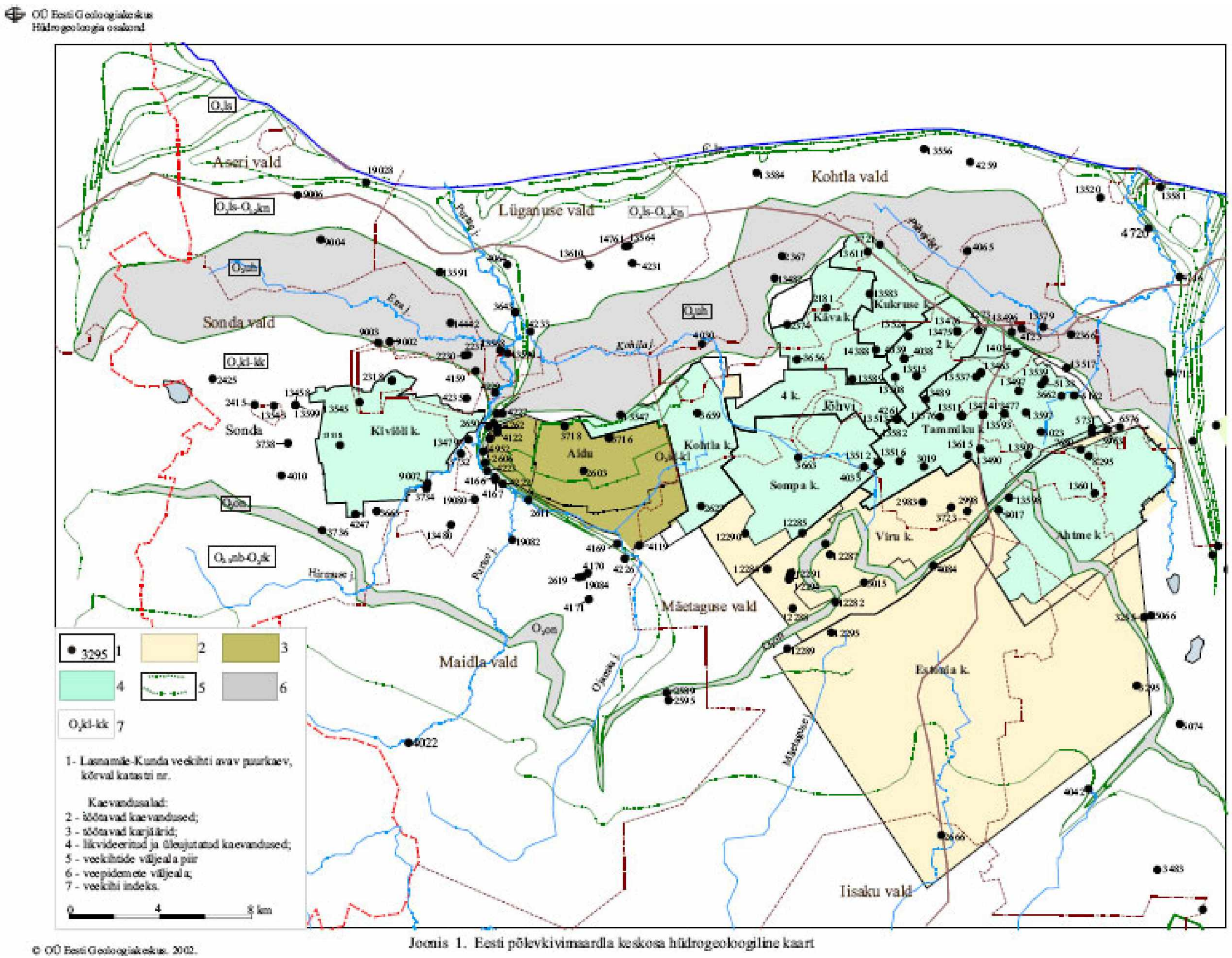


Figure 3. Location of groundwater wells [Savitski L., 2003].

Appendix VIII

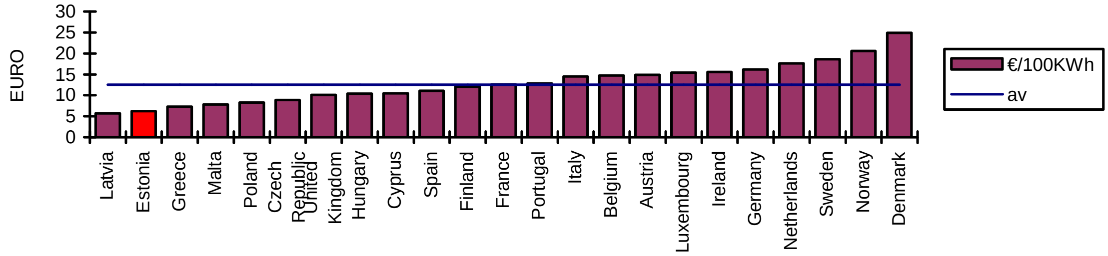


Figure 1. Electricity prices for households, January 2004 [Electricity prices for EU households...].

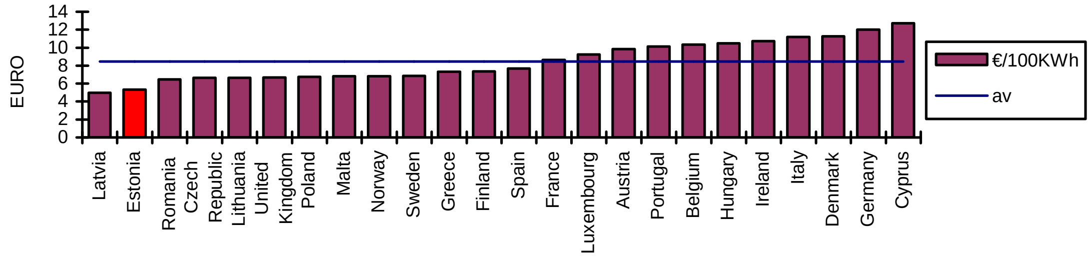


Figure 2. Electricity prices for industry, January 2004 [Electricity prices for EU industry...].

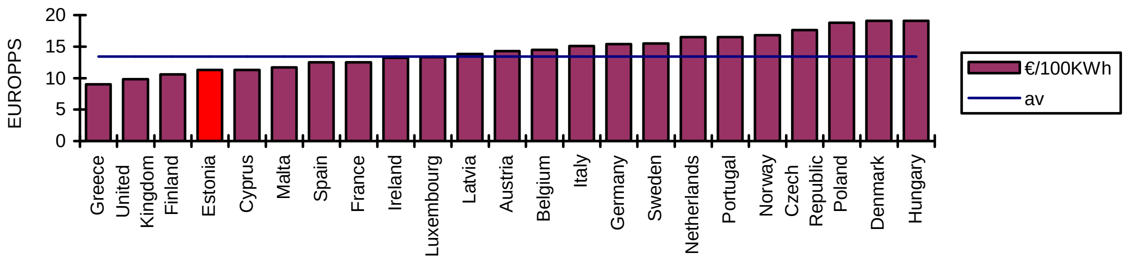


Figure 3. Electricity prices for households, January 2004 [Electricity prices for EU households...].

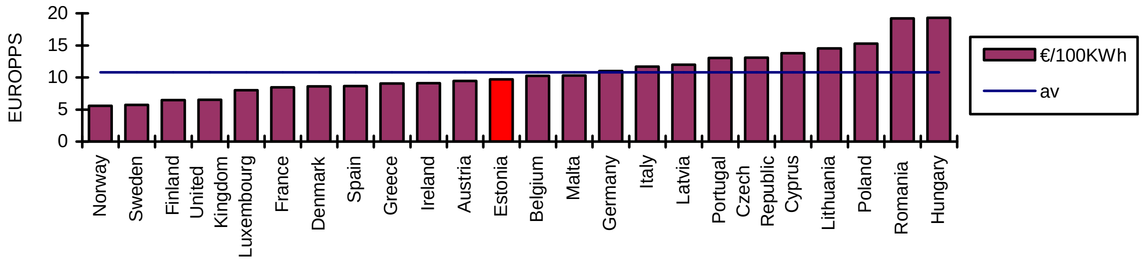


Figure 4. Electricity prices for industry, January 2004 [Electricity prices for EU industry...].

Appendix IX

Table 1. Investments into power plants according to AS Eesti Energia's plans [Investment plan…, 2004]

thousand EEK

	2004/2005	2005/2006	2006/2007	2007/2008	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013
Investments into Narva PPs	**539,659**	**200,000**	**200,000**	**3,080,000**	**3,665,000**	**400,000**	**200,000**	**1,100,000**	**2,300,000**
Renovation of oil shale ash removal system				1,300,000	1,300,000				
BPP reserve boiler-house	217,000	66,573							
Renovation of the system of fuel feeding	60,000	68,000	72,000						
2. CFB power unit (215 MW)	101,000								
3. CFB power unit (300 MW)				1,600,000	2,200,000	200,000			
4. CFB power unit (215 MW)								900,000	1,200,000
5. CFB power unit (215 MW)									900,000
6. CFB power unit (215 MW)									
7. CFB power unit (215 MW)									
Other investments into NPPs	161,659	65,427	128,000	180,000	165,000	200,000	200,000	200,000	200,000
Investments into Iru CHP	**59,330**	**12,160**	**8,730**	**342,100**	**60,000**	**25,350**	**25,692**	**26,026**	**26,352**
LowNO$_X$ furnaces	1,600	0	40 000	35,800	47,250				
CHP plant in Tallinn (40MW)				300,000					
Gas turbine (150MW)									
Gas turbine (100MW)									
Other investments into IruPP	57,730	12,160	8,730	6,300	12,750	25,350	25,692	26,026	26,352
Investments into Kohtla-Järve CHPs	**19,915**	**10,100**	**8,285**	**7,800**	**8,000**	**8,000**	**8,000**	**8,000**	**8,000**
Investments into renewable energy	**0**	**660,000**	**700,000**	**240,000**	**240,000**	**0**	**0**	**0**	**0**
Wind park (50MW)		400,000	400,000						
Wind park on Balti PP ash disposal area				240,000	240,000				
Ahtme CHP		260,000	300,000						
Investments into "AS Eesti Põlevkivi"	**280,000**	**250,000**	**220,000**	**200,000**	**200,000**	**200,000**	**200,000**	**200,000**	**200,000**
Total investments into oil shale and electricity production	**898,904**	**1,132,260**	**1,137,015**	**3,869,900**	**4,173,000**	**633,350**	**433,692**	**1,334,026**	**2,534,352**

	2013/2014	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	Total	
Investments into Narva PPs	**2,400,000**	**2,400,000**	**1,500,000**	**300,000**	**200,000**	**200,000**	**18,684,659**	**72%**
Renovation of oil shale ash removal system							2,600,000	10%
BPP reserve boiler-house							283,573	1%
Renovation of the system of fuel feeding							200,000	1%
2. CFB power unit (215 MW)							101,000	0%
3. CFB power unit (300 MW)							4,000,000	15%
4. CFB power unit (215 MW)	100,000						2,200,000	8%
5. CFB power unit (215 MW)	1,200,000	100,000					2,200,000	8%
6. CFB power unit (215 MW)	900,000	1,200,000	100,000				2,200,000	8%
7. CFB power unit (215 MW)		900,000	1,200,000	100,000			2,200,000	8%
Other investments into NPPs	200,000	200,000	200,000	200,000	200,000	200,000	2,700,086	10%
Investment into Iru CHP	**26,681**	**27,014**	**927,000**	**627,000**	**28,000**	**28,350**	**2,249,785**	**9%**
LowNO_X furnaces							84,650	0%
CHP plant in Tallinn (40MW)							300,000	1%
Gas turbine (150MW)			900,000				900,000	3%
Gas turbine (100MW)				600,000			600,000	2%
Other investments into IruPP	26,681	27,014	27,000	27,000	28,000	28,350	365,135	1%
Investments into Kohtla-Järve CHPs	**8,000**	**8,000**	**8,000**	**8,000**	**8,000**	**8,000**	**134,100**	**1%**
Investments into renewable energy							**1,840,000**	7%
Wind park (50MW)							800,000	3%
Wind park on Balti PP ash disposal area							480,000	2%
Ahtme CHP							560,000	2%
Investments into “AS Eesti Põlevkivi”	**200,000**	**200,000**	**200,000**	**200,000**	**200,000**	**200,000**	**3,150,000**	**12%**
Total investments into oil shale and electricity production	**2,634,681**	**2,635,014**	**2,635,000**	**1,135,000**	**436,000**	**436,350**	**26,058,544**	**100%**

Table 2. Investments into the transmission and distribution network according to AS Eesti Energia's plans [Investment plan…, 2004]

thousand EEK

	2004/2005	2005/2006	2006/2007	2007/2008	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013
Investments into Transmission Grid (Põhivõrk)	658,084	666,052	469,843	492,120	402,896	528,500	526,760	485,950	479,050
Investments into Distribution Grid (Jaotusvõrk)	750,000	765,000	778,005	789,675	800,731	811,140	820,874	829,902	838,202

	2013/2014	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	Total
Investments into Transmission Grid (Põhivõrk)	488,300	472,270	461,100	454,480	505,870	505,490	**7,596,765**
Investments into Distribution Grid (Jaotusvõrk)	846,584	855,050	863,601	872,237	880,959	889,769	**12,391,729**