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ESTONIAN OIL SHALE RESOURCES CALCULATED BY GIS METHOD

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A digital map of Estonian oil shale mining was created for joining the data about technological, environmental, and social limitations in the deposit. For evaluating potential resource of oil shale, based on borehole database, its amount, tonnage and energy were calculated. Thereafter the quantity of economical oil shale for power plants and shale oil resource were calculated. Energy rating is the most important factor for determining oil shale reserves in the case of using it for electricity generation. In the case of oil production, data on oil yield and potential resources in oil shale are the most important figures to determine the value of the deposit. Basing on the models, oil resource has been calculated. Resource data can be used for composing master plans for the deposit considering both power generation and oil production. The data can be also used for composing development plans of mines and for logistics calculations.

Introduction

Oil shale bed in Estonia is deposited in the depth of 0–100 m with the thickness of 1.4–3.2 m in the area of 2,884 km^2 (Fig. 1). The mineable seam consists of seven kukersite layers and four to six limestone interlayers. The layers are named A–F_1. The energy rating of the bed is 15–45 GJ/m^2.

Oil shale mining in then Estonia Province started in 1916; it was extracted in surface mines using the opencast method. Underground mining started in 1922. Room-and-pillar mining, which is the only underground oil shale mining method today, was started in 1960. During the years 1971–2001 in some mines longwall mining with shearers was used. In total ten oil shale surface mines and thirteen underground mines have been in operation. Probability of opening new operations is high if oil shale processing or cement productions become more active.

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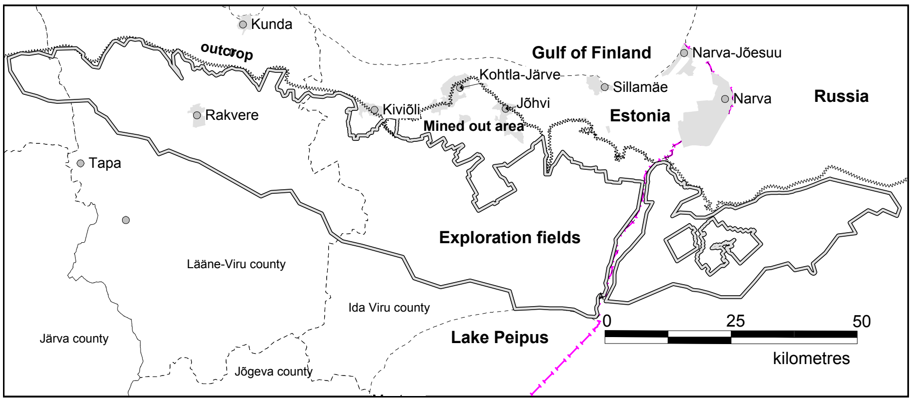


Fig. 1. Baltic oil shale area

The Criteria of the Oil Shale Reserve

The criteria of the oil shale reserve are: energy rating, calorific value of the layers, thickness and depth of the seam, location, available mining technology, world price of competitive fuel and its transporting cost, oil shale mining and transporting cost. In addition, nature protection areas are limiting factors for mining. The economic criterion for determining Estonia's kukersite[*] oil shale reserve for electricity generation is the energy rating of the seam in GJ/m^2. It is calculated as the sum of the products of thickness, calorific values and densities of all oil shale layers $A–F_1$ and limestone interlayers. A reserve is mineable when energy rating of the block is at least

Table 1. **Estonian Oil Shale Reserves, M tons, January 1, 2002**

Reserves	Range of mineability	
	Economic	Subeconomic
	Cut-off-grade – energy rating of bed, GJ/m^2	
	35	25
Range of exploration:		
Measured & indicated	1,186	1,760
Indicated & inferred	302	1,751
Total	1,488	3,511
Including:		
Operating mining fields:		
Measured	513	150
Inferred	172	36
Abandoned mining fields:		
Measured	17	73
Inferred	5	7

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

35 GJ/m^2, and subeconomic if energy rating is 25–35 GJ/m^2. According to the Balance of Estonian Natural Resources, the oil shale reserve was 5 billion tonnes in the year 2002. Economic reserve was 1.5 billion t and subeconomic – 3.5 billion t (Table 1). These numbers apply to oil shale usage for electricity generation in power plants and are calculated only by oil shale layers, which is fiction because in most cases the total bed is used for combustion. In the case of wide-scale using of oil shale for cement or oil production, the criteria must be changed.

The presented official reserve data are not reliable as seen in Fig. 2. Reliability is only 50 % on the lines of 35 and 25 GJ/m^2, as well as in any other point on the deposit. As well known in practice, the reliability is sufficient beginning with 70–85 %. In fact about 35 % from the reserve of the *Estonia* mining field are below economic level.

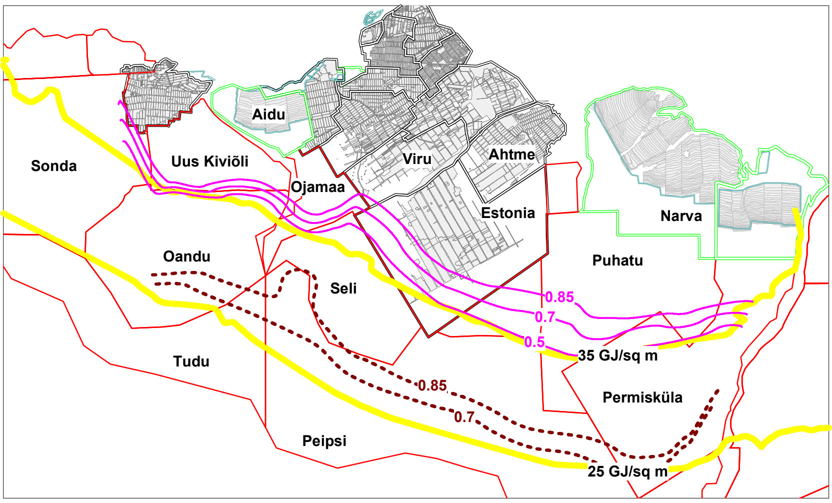


Fig. 2. Reliability of reserves

Oil shale resource depends on the consumption amount. The graph in Fig. 3 shows the age of oil shale resources if resource is calculated by criteria proceeding from electricity generation. If the output level is ten million tonnes per year, the economic reserve in mining fields of operating mines will last for 25 years. In the case of technological development and changing environmental limitations, this period could prolong to 45 years. When accounting all economic reserve, the period of mining will last 60 years with 10 Mt production.

The following conclusions could be made after evaluating the age of resources:

- Economic reserve will last until the year 2025
- The reserve must be recalculated using new criteria in the case of wide-scale oil production

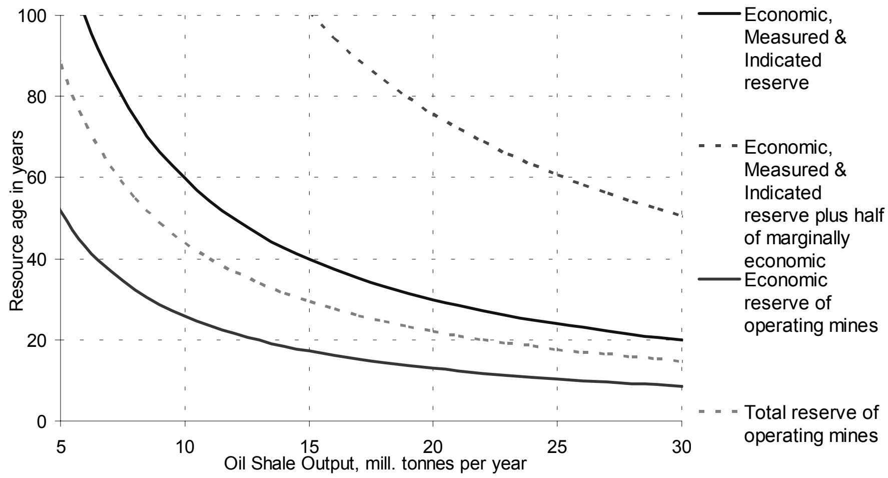


Fig. 3. Age of oil shale resources

Modeling

Basing on geological data, several grids of oil shale layers and seams were created (height, thickness, in-place tonnage, energy rating, overburden thickness and stripping coefficient).

Oil Shale Resource

For evaluating potential resource of oil shale, its amount, tonnage and energy must be calculated. Then the quantity of economical oil shale for both electricity and oil production is calculated. Assuming that Estonia deposit is a combination of current exploration fields, the polygon shown in Fig. 4 marks the deposit area covering 2,884 km^2. The quantity of the oil shale seam could be calculated by extracting seam thickness and corresponding areas from the created isopachs using SQL query.

Inverse distance weighting (IDW), triangulation with smoothing, natural neighbour, rectangular interpolation and Kriging methods could be used for interpolation. IDW Interpolation can be used because the errors of the initial data exceed smoothing level of the method. Smoothed isopleths give a more clear overview of the deposit and allow to extrapolate the data beyond the data points.

Calculating and interpolating energy rating per square meter are necessary for energy resource evaluation. The graph based on the model (Fig. 4) shows the energy ranges of oil shale of the deposit, the quantity already mined out and the available resource. Most of the mined-out seam has had the energy rating value over 35 GJ/m^2 (Fig. 5). Energy rating of the seam is an essential argument for economical calculations.

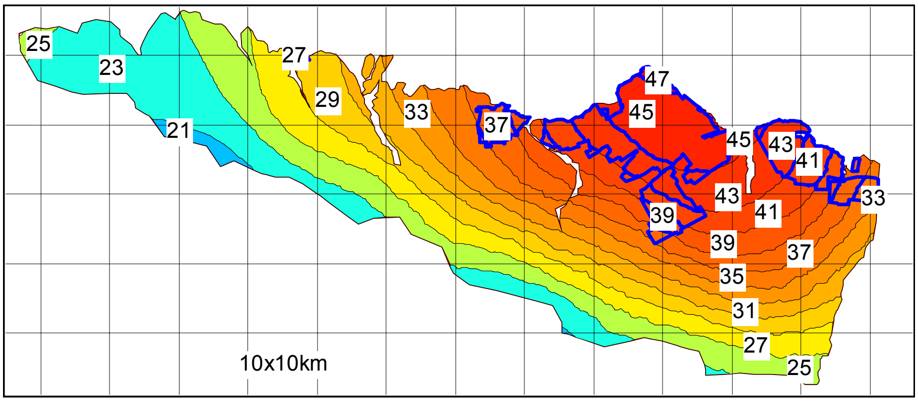
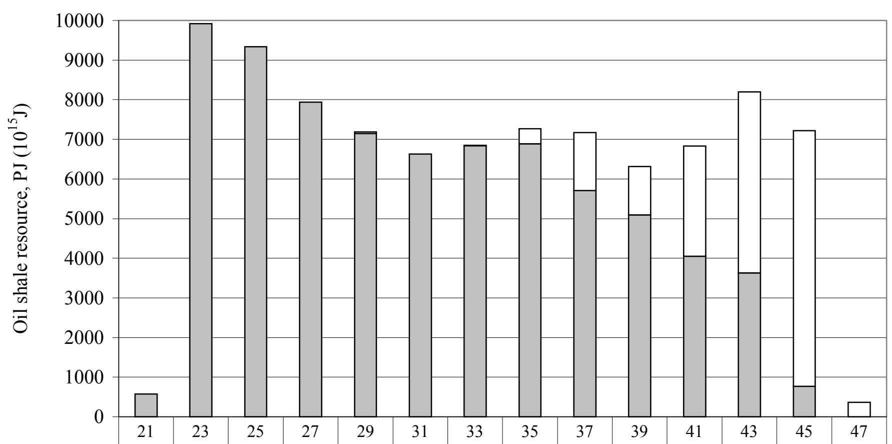


Fig. 4. Energy rating of oil shale, GJ/m^2. The resource over 35 GJ/m^2 is oil shale economic reserve. Bold contours in north mark the mined-out area

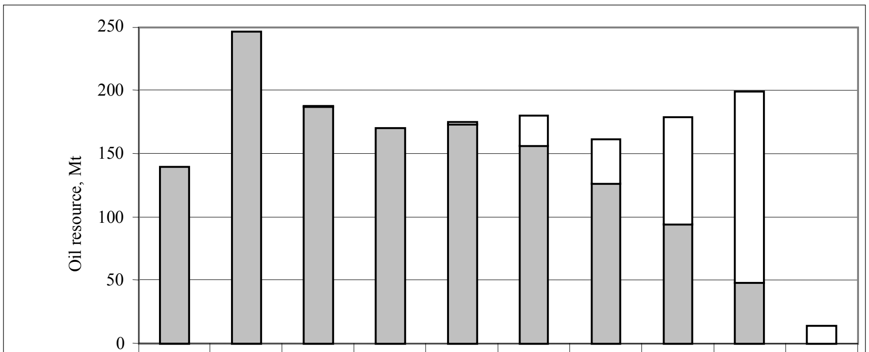


	21	23	25	27	29	31	33	35	37	39	41	43	45	47
□ Mined out PJ	0	0	0	0	37	0	7	382	1465	1219	2790	4570	6451	362
■ Unmined PJ	570	9923	9340	7939	7150	6628	6844	6886	5704	5097	4047	3630	768	0

Energy rating of oil shale, GJ/m^2

Fig. 5. Oil shale resource of the Estonia deposit in PJ. Most of the mined-out seam has had energy rating over 35 GJ/m^2

The models enable to present the graphs of energy rating showing its extent and ranges. Energy rating is the most important factor for determining oil shale reserve in the case of using it for electricity generation. In the case of oil production, the most important figures are oil yield and its resource. Basing on the models, oil resource has been calculated and is presented in Fig. 6.



	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85
□Mined out Mt	0	0	1	0	2	24	34	85	151	14
■Unmined Mt	140	247	187	170	173	156	127	94	48	0

Oil yield, t/m ^{2}

Fig. 6. Shale oil resource, million tonnes, in ranges of oil yield

Choosing between various interpolation methods showed that IDW gives the most reliable figures for oil shale tonnage with average figures of the reserve blocks. Natural Neighbour regions and Kriging are the more suitable interpolation methods when using more detailed data and blocks. Rectangular Interpolation is unsuitable in the case of irregular mesh of the initial data. All methods give 2.3 m for oil shale seam average thickness except rectangular interpolation that gives 2.1 m and 11 % deviation. Other methods give deviation from 1 to 3 %, which are smaller than errors of the initial data.

Calculated Data of the Deposit

The main results of the calculations are data models of the deposit such as isopleths and 3D drawings of mining conditions like seam thickness, seam depth, calorific value of oil shale and oil yield. The main possible calculations basing on oil shale bedding models are: choosing optimum mining location, dynamics and statistics of the mining phenomenon, evaluation of oil shale quantity, energy and oil reserve. IDW method gives satisfactory data for the deposit overview (Table 2), other suitable methods can be used for modeling with all initial drill hole data in the case of resource calculations for some specific location.

One of the preliminary results of the modeling is obtaining cost data. Reinsalu has applied his methodology and study to the current deposit model and shown the cost of oil shale tonne over the deposit. The cost is 100 kroons per tonne in the center of *Estonia* mining field (Fig. 7). Oil cost *in situ* is 100 % for cost of the tonne in the centre of Estonia mining field and according to Fig. 8 can be applied to other parts of the deposit.

Table 2. **Data of Estonia Oil Shale Deposit Calculated with IDW Method**

Parameter	Unmined	%	Mined-out	%	Total or average
Area, km^2	2476	86	409	14	2,884
Oil shale tonnage, Mt	10,139	84	1,900	16	12,039
In-place tonnage, t/m^2	4.1	98	4.6	111	4.2
Specific weight, t/m^3	1.8	101	1.7	96	1.8
Quantity, Mm^3	5,657	84	1,116	16	6,774
Energy, PJ	74,524	81	17,283	19	91,808
Energy rating, GJ/m^3	30	95	42	133	32
Oil resource, Mt	1,342	81	311	19	1,652
Oil yield per m^2, t/m^2	0.54	95	0.76	133	0.57
Oil yield, t/t	0.13	96	0.16	119	0.14

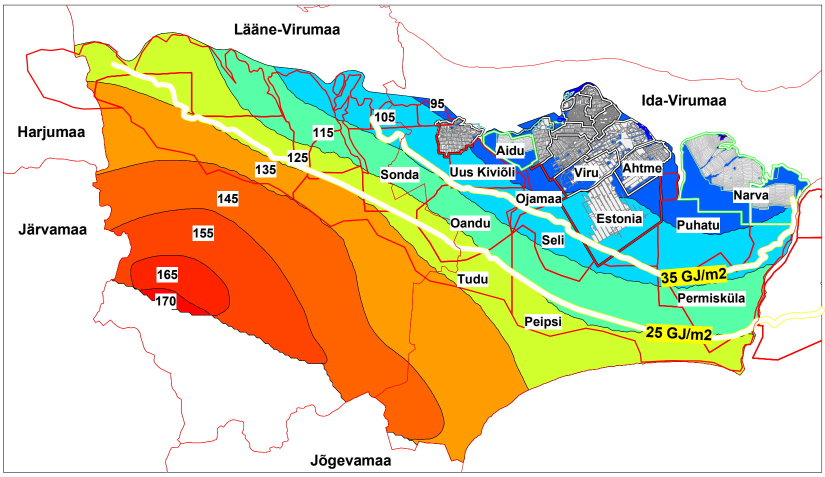


Fig. 7. Oil shale cost, Estonian kroons

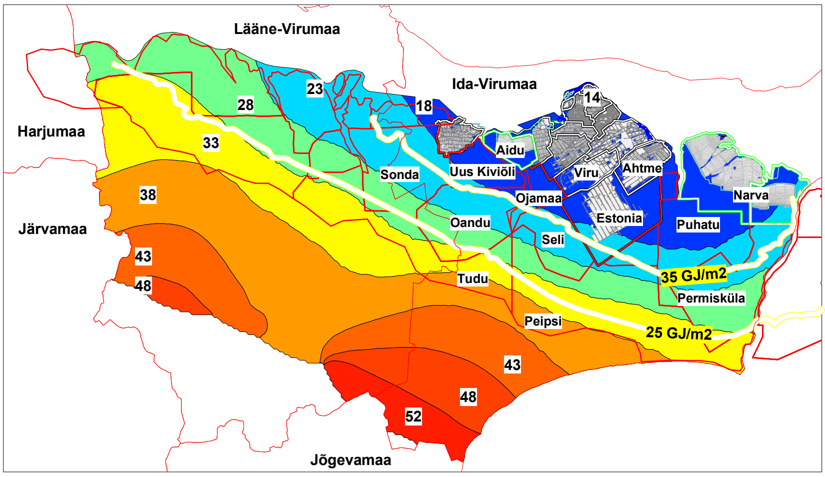


Fig. 8. Shale oil cost, USD/barrel

Conclusions

Modeling with GIS methods together with geostatistical analysis is an effective and promising method for re-evaluating the resources of Estonian oil shale as well as of any other flat-laying deposit. Modeling with available digital geographic and technogenic data gives the possibility to analyze the resource at any level of details.

Ascknowledgements

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