

# Environmental impact of oil shale mining

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Received: 9 February 2016 / Accepted: 9 August 2016 / Published online: 25 August 2016  
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**Abstract** Oil shale mining has impact on the environment. In Estonia, 100 years of oil shale mining history provides sufficient experience and acknowledgement for estimating environmental impact for the future. The mining depth is increasing, and mining activities are moving from surface to underground mines. Environmental impact of oil shale mining with and without backfilling for 20, 24 and 28 Mt/y production rate was evaluated for the future and compared with the past. Ground stability, landscape properties, mining waste management, usage of resources and mining losses, water management with water quality and depression cones, noise and dust were analysed on 7-point impact points scale. The aim of this study was to create criteria for estimating environmental impact of oil shale mining.

**Keywords** Oil shale · Mining technology · Environmental impact · Mining waste · Water · Landscape

## Introduction

Oil shale deposit in Estonia is 135-km-long lens-shaped flat body. Most of the deposit is located in Ida-Viru County in north-eastern part of Estonia (Fig. 1).

Most of the electricity and heat, oil and chemical products produced in Estonia are made from oil shale. Half of the oil shale comes from underground mines. The

mining depth is increasing as the shallower part of the deposit has been mined out. Mining activities are moving to underground mines, and mining technologies have to be improved in the future (Karu et al. 2008; Väizene et al. 2013). The deepest mine is Estonia mine with 75 m depth.

Mining companies have interest in increasing the yearly production of oil shale. Since 1991, the highest yearly production of oil shale mining has not exceeded 17 Mt/y. Environmental impact of mining of oil shale up to 28 Mt/y has not been estimated before.

The aim of the study was to compare environmental impact of different mining capacities. Different variants were defined, and technologies were analysed. The study evaluates present and past stage in two variants (variant no 4 and 5, Table 7) and future developments in other variants. Mining areas were set for years 2016–2030 (Fig. 1). As the expected mining capacity increases up to 28 Mt/y, underground mining capacities will increase more than that of surface mining and have stronger influence. In addition, criteria for estimating environmental impact of oil shale mining were created. A number of influences, such as mining waste management, ground stability, landscape properties, usage of resources, water management, noise and dust, were analysed (Valgma et al. 2006).

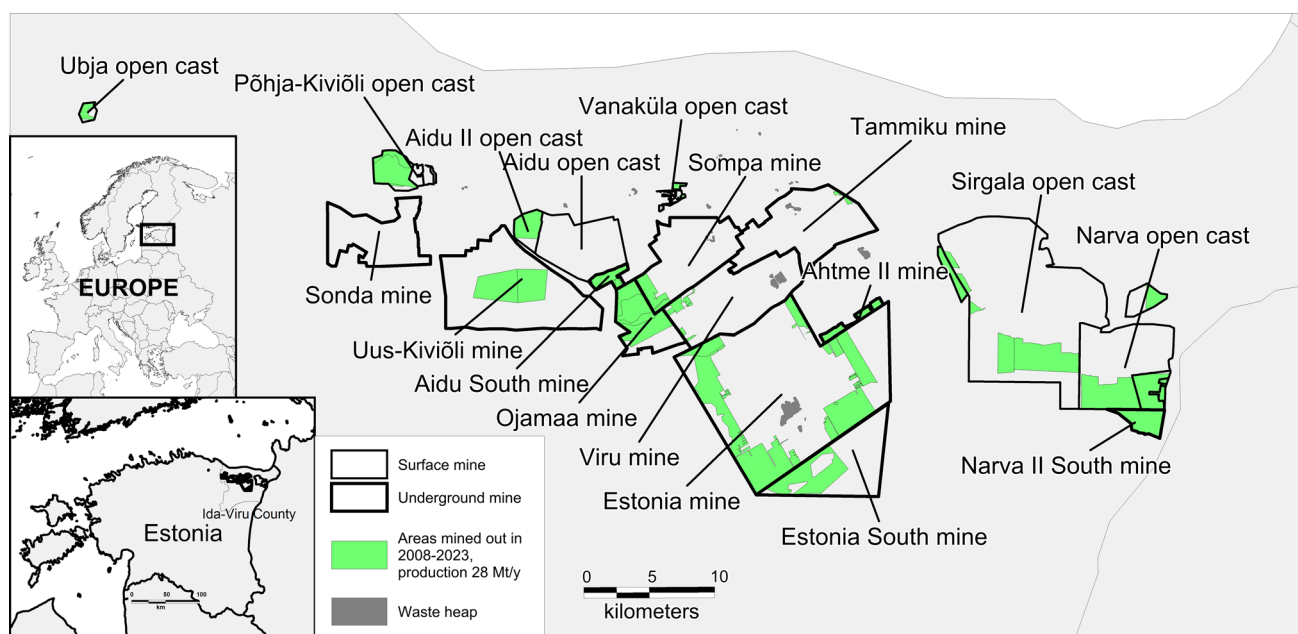
## Methods

For environmental impact assessment, different methodologies, environmental aspects and dynamic tools can be used (Castilla-Gomez and Herrera-Herbert 2015; Rikhtegar et al. 2014). Previous researchers have used for example three groups of criteria in evaluation of geo-environmental impact of mining for limestone mine: geo-hazards risks, environmental risks and resource damages. For current

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**Fig. 1** Location of Estonian oil shale mining district and areas to be mined out in 2008–2023 with production 28 Mt/y and location of waste heaps

study, computer modelling spatial GIS systems and models of the influences were used (Karu et al. 2013; Robam et al. 2011).

Environmental impact of oil shale mining with and without backfilling (Valgma et al. 2013a) for 20, 24 and 28 Mt/y production was evaluated (Fig. 1). In underground mining room and pillar mining technology with roof support and longwall mining technology with roof collapse and on the surface open-cast mining was evaluated. Yearly production rate was chosen based on the potential usage possibilities for oil and electricity generation. Additionally, variant 4 about mining influence in year 2008 and variant 5 about mining impact until year 1991 were analysed. In 1991, Estonia established its independence and mining laws and regulations were changed (Table 7).

Impact points on 7-point scale were ascribed to every impact field based on the influence. Seven-point scale was chosen as minimum amount for describing the impact in detail enough. One point has the weakest influence, and 7 points strongest. The 7-point scale was discussed and agreed with the representatives from oil shale industry for creating understandable and comparable evaluation of past, current and future oil shale mining.

## Landscape

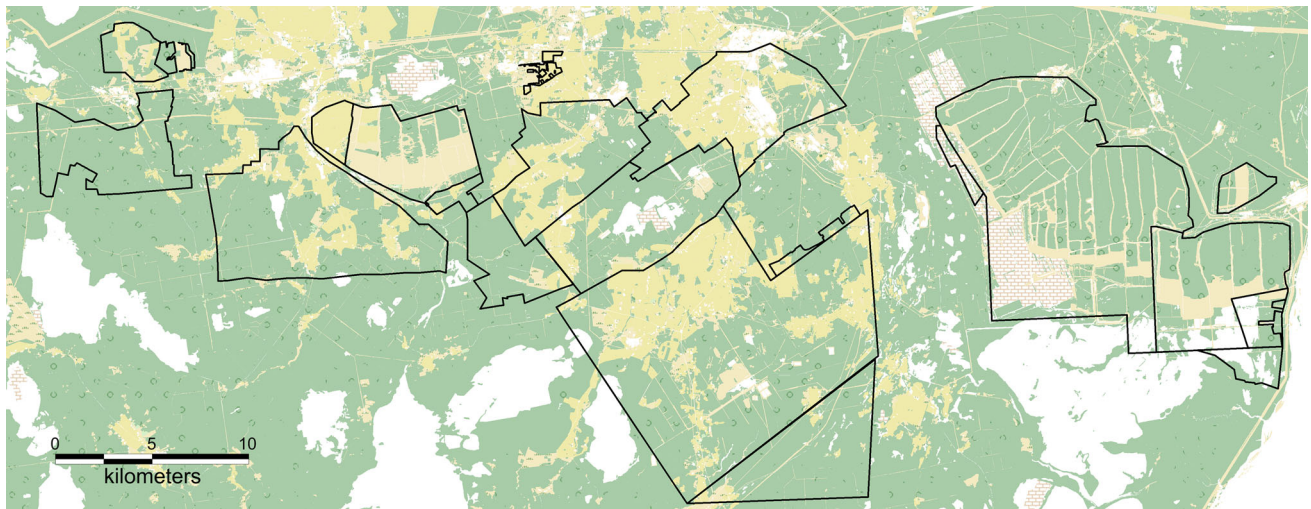
Oil shale mining area is divided by two main mining methods, surface and underground methods. The reason for choosing underground or surface mining technology is

overburden thickness, but historically and in the future other factors have strong influence as well (Valgma 2000). These are technology being used, economical situation, mining traditions and preferences of mining companies. Some areas like southern part of Aidu open cast and southern part of Narva open cast or southern part of Ubja open cast could be mined with either surface or underground methods (Figs. 1, 2, 3).

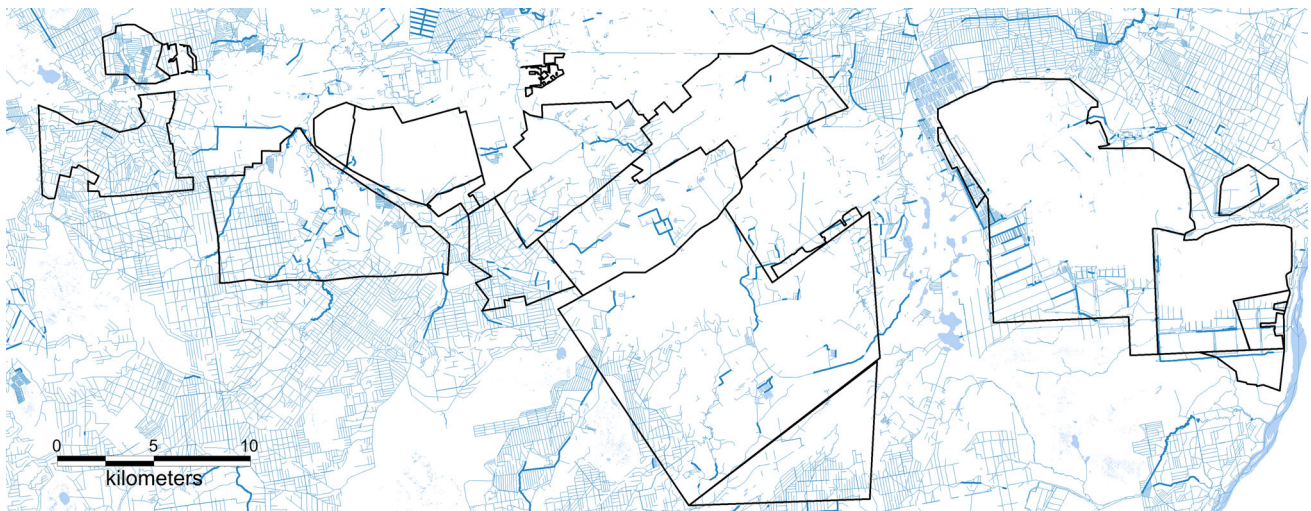
Source data for evaluating mining influence come principally from two directions, from surveys of mining companies, or from state-made or ordered surveys. In current study, we concentrated on state data that are more systematic and available for the public (Fig. 4). The main data are taken from Estonian National Topographic Database (Estonian National Topographic Database. Estonian Land Board 2007).

The influence of mining on the landscape could be evaluated by measurable or by expert figures. The measurable figures are geometrical and mechanical figures. Some of them are limiting factors, also being strong evaluation criteria like unstable sidewalls or ground. Many figures are being given by expert opinions such as good, nice, bad or ugly waste rock heap. The landscape evaluating for mining has not been fully standardised, and the common criteria do not exist.

Some of the criteria that are used are dealing with land usage. In case of strip mining, the angle of wall of the trenches in mined out area must not exceed the angle of repose of the material. The main recommendations in Estonian laws are dealing with angle of the ground



**Fig. 2** Land cover on study area



**Fig. 3** Water on study area

surface after strip mining. The maximum angle in case of afforestation can be eight degrees, and the water level must be at least 0,7 m deeper than ground surface. In case of farming, these figures are 3 degrees and one metre. The main categories in case of underground mining that are being used are steady, stable, quastable and subsided land (Reinsalu and Valgma 2003; Erg et al. 2003).

For evaluating mining impact on the landscape, different mining conditions, mining technologies and their landscape are evaluated. Both the extent and strength of the impact are evaluated (Table 1). In current study, we analyse the whole area of Estonian oil shale deposit as it is, focussing on changes in mining capacity or mining technology. The questions of permitting mining under wetlands or in nature

protection areas are covered with the levels of the influence, but are out of the scope of current study.

### Resources

An analysis of resource usage is important for estimating the amount of oil shale reserve to be used. Different tools can be used in assessing mining impact under protected areas (Marnika et al. 2015). In Estonia, mining under protected areas in underground or surface mines are prohibited and that amount of oil shale reserve is not included into assessment.

Impact points of resource usage are formed by resource index and the total losses. Losses depend on mining



**Fig. 4** Grid of the census data on mining areas

method which is related to depth of mining (Orru et al. 2013b; Väizene et al. 2015) and geological dislocations (Sokman et al. 2008). Mining on the surface could limit losses less than 20 % and in underground mines up to 50 % (Valgma et al. 2013b) (Table 2).

## Waste

Evaluating oil shale waste rock impact, amount of waste rock and organics in waste rock heap has to be considered. Both impacts give the total assessment by the arithmetic average (Table 3).

## Water

Not regulated, abandoned or closed mines could cause negative impact on the surface water and the groundwater quality. In Europe, the following directives regulate the monitoring and protection of surface and groundwater:

- Commission Directive 2009/90/EC (COMMISSION DIRECTIVE 2009/90/EC. Laying down...)
- Commission Directive no 2008/105/EC (DIRECTIVE 2008/105/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL. On environmental...)

Evaluating oil shale mining impact on groundwater and surface water, impact of hydrogeology, hydrology and hydrochemistry has to be considered (Table 4):

- Changes in groundwater level (groundwater depression cone area)
- Impact on surface water (groundwater pumping)
- Changes in groundwater and surface water chemical components

Data for analysing groundwater and surface water impact are collected from national observation net for groundwater and surface water, and also mining companies observation net is included (Fig. 5).

All described components are related and observable in three stages: before mining activity, during oil shale mining and after mining activities. Therefore, evaluation was set up in the following steps: impact of groundwater depression cone, groundwater pumping and water chemical components (Table 4).

Impact points for groundwater depression cone are evaluated by total area of groundwater depression cone in square kilometres. For example, if depression cone area is between 200 and 250 km<sup>2</sup> then it gives 2 impact points (Table 4). Impact points for groundwater pumping are depending on the amount of pumped water in million m<sup>3</sup>. For example, if pumped out groundwater from surface mine and underground mine is between 200 and 250 million m<sup>3</sup> then it gives 6 impact points (Table 4).

For assessing the impact of oil shale mining on surface and in groundwater, there are two impact factors: radius of drawdown cone and requirements for the groundwater chemical composition.

The chemical characteristics of groundwater and surface water exceeding the maximum permitted limits must be

**Table 1** Matrix of landscape evaluation

Impact points	Description	Surface mine	Explanation	Underground mine	Mining depth	Explanation
1	No impact on the landscape. Ground is stable. In case of underground mining, mineshaft and entrance workings will be used for secondary purposes (Kohtla mine museum) or will be closed and reclaimed to the premining natural state	–	There are no such surface mines	1	13...40 m	Stable and steady area
2	Impact on the landscape is limited. Ground surface could subside less than 5 cm. Waste rock or overburden rock is placed aesthetically or screened by vegetation to be hidden for main traffic roads	2	Well-reclaimed surface mines like Ubja and Kohtla-Vanaküla open-cast mines	2	40 m	Quasistable deeper mines
3	Impact on the landscape is noticed. Some subsidences occur. Unhandled waste or overburden spoils can be seen from main traffic roads	3	All surface mines that are reclaimed properly	3	0...40 m	Non-room and pillar mining
4	Short-term impact on the landscape is strong. Long-term reclaiming is aesthetical and suitable for the area	4	All surface mines reclaimed properly	4	0...40 m	Subsided land
5	Impact on the landscape is strong but not disturbing	5	Reclaimed surface mines without disturbing pollution and instability	5	0...12 m	Quasistable shallower mines
6	Short-term impact on the landscape is very strong. Long-term state is unnatural, but tolerable (waste rock heaps)	6	Deeper reclaimed open cast mines	6	0...40 m	Area with subsidences or potentially subsiding area
7	Landscape is spoilt and impossible to reclaim with reasonable cost (Trenches of Maardu phosphate rock mine)	7	Not reclaimed surface mines, potentially ignitable or polluting	7	0...12 m	Area with subsidences or potentially subsiding shallow area

**Table 2** Matrix of resource usage evaluation

Impact points	Resource index	<0.5	0.5...0.75	0.75...1	1...1.25	>1.25
	Resource usage	Losses, %				
1	Great	<20				
2	Very good	20...30	<20			
3	Good	30...50	20...30	<20		
4	Moderate		30...50	20...30	<20	
5	Bad			30...50	20...30	<20
6	Very bad				30...50	20...30
7	Worst					30...50

monitored. Possible criteria could be to limit values and threshold values presented in the legislation and divide into different impact points, e.g. when the characteristic exceeds the permitted maximum limit, the situation is the worst equal to 7 points in the scale (Table 4). For example, the underground mines with filled drifts are closed water reservoirs and therefore receive 2 impact points (Table 4). Impact points from 4 to 6 cannot be given for evaluating groundwater and surface chemistry.

**Noise and dust**

Methods used for measuring the noise are different worldwide. In Australia, measurements are taken using dB(A) scale (Guidelines for Noise Control...). In Estonia, noise measuring is regulated by standard EVS-ISO 1996-1:2006 (Acoustics. Description, measurement...). The standard frequency weightings are A-weighting and C-weighting specified in IEC 61672-1, and the standard

time weightings are F-weighting and S-weighting specified in IEC 61672-1. Main sources of noise in mining are transportation trains, conveyors, motor transport, mining machinery, blasting, ventilators of ventilating systems, ventilating shafts.

The components of matrix of noise evaluation are threshold of noise and number of residents (Fig. 6). Table 5 presents definitions of noise impact points.

During analysis, it appeared that for reducing impact of noise generated by the railroad transportation, trees must be planted or noise barriers built by the side of railways. In surface mines, dumps must be placed in direction of residential areas. Conveyors should be used instead of railroad transport (Orru et al. 2013a).

**Table 3** Matrix of waste rock evaluation

Impact points	Amount of oil shale waste rock production and storage in waste rock heap during oil shale separation process, million tonnes/year	Amount of organics in oil shale waste rock heap <sup>a</sup> that has been stored in waste rock heap during separation process, million tonnes/year
1	up to 4	up to 0.050
2	up to 4.5	up to 0.100
3	up to 5	up to 0.150
4	up to 5.5	up to 0.200
5	up to 6	up to 0.250
6	up to 6.5	up to 0.300
7	up to 7	up to 0.350

<sup>a</sup> In time frame from 2013 to 2023, the organic content in waste rock is considered 4 %

Before 1991, the main sources of noise were blasting with larger explosive charges without delays. As for transport, the noise was generated by motor transport, trains and cable transport. Besides, the separation plants were sources of noise. There were no legislative acts regulating the noise (Toomik and Tomberg 1997).

After 1991, sources of noise are blasting, motor transport, freight trains, ventilators and conveyors. The noise level is regulated by legislative acts. The separation equipment is located in buildings and therefore can be disturbing, but is not hazardous. Trees have been planted to mute the noise.

## Dust

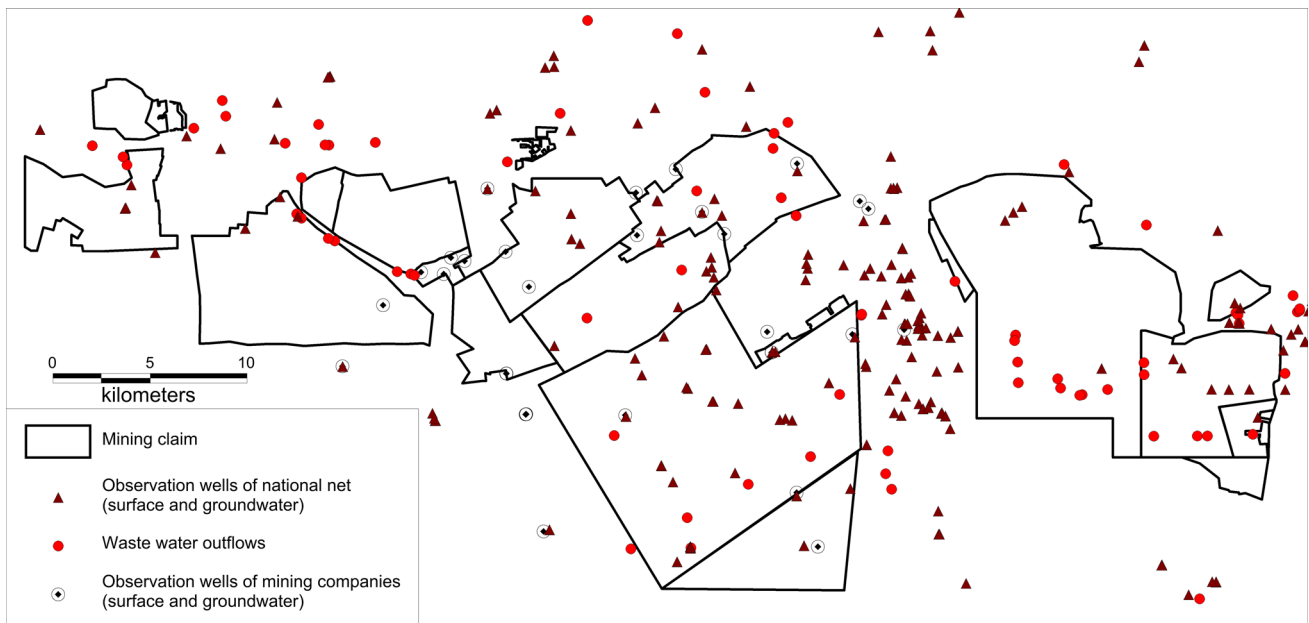
In the USA, the dust measuring methodology suggests to take into consideration the following indicators (Kissell 2003):

- Air has to move
- The distance between measuring points and dust source is 30 m
- The speed of air is between 0.25 and 4 m/s
- The measurements should be taken during normal mining period

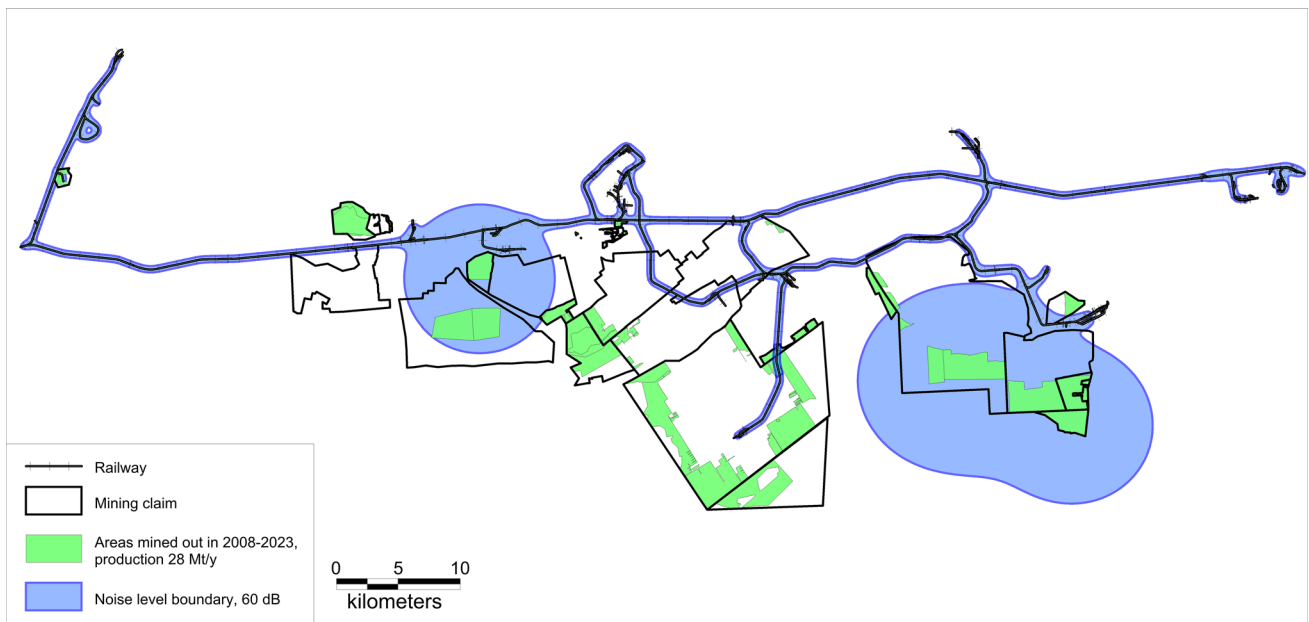
For mitigating the dust, the roads in the surface mines must be humidified. The issuing exhaust systems of plants must be equipped with filters. If possible, blasting should be postponed when the wind blows from unsuitable direction.

**Table 4** Matrix of groundwater depression cone area and chemistry regulation in oil shale deposit evaluation

Impact points	Total area of groundwater depression cone, km <sup>2</sup>	Pumped groundwater from surface mine and underground mine, million m <sup>3</sup> /year	Groundwater and surface chemistry regulation
1	<200	No oil shale mining in the region, no groundwater pumping	Chemical components in water are at the same value as it is described in directives
2	200 ≤ 250	≤50	Some described chemical components are exceeding the limit values in directives. (Underground mines are filled with water)
3	250 ≤ 300	50 ≤ 100	Some described chemical components are exceeding the limit values in directives
4	300 ≤ 350	100 ≤ 150	N/A
5	350 ≤ 400	150 ≤ 200	N/A
6	400 ≤ 450	200 ≤ 250	N/A
7	>450	>250	All described chemical components are exceeding the limit values in directives



**Fig. 5** Location of water outflows in the mining district



**Fig. 6** Noise pollution of transportation and drilling and blasting works with production 28 Mt/y, 60 dB

As for the railroad transport, the dust can be reduced by covering up the wagons and lowering the speed of the train. Conveyor transport should be used instead of railroad transport. When using filling technology, the waste rock should be crushed underground.

Before 1991, dust was created by blasting. The motor transport and trains also created dust. Besides, the separation plants were sources of dust. Annually, 193 thousand

tonnes of solid particles PM10 were emitted (Liblik and Kundel 1995).

After 1991, dust was generated by blasting, motor transport and trains. According to the review (Liblik and Kundel 1995), 24 thousand tonnes of solid particles was emitted. The dust of separation plants did not spread outside the plants. To restrain the distribution of dust, the surroundings of dust sources have been afforested

**Table 5** Matrix of mining-related noise evaluation

Impact points	Threshold of noise	Number of residents	Remark
1	Not exceeded	No residents	Threshold level of noise is not exceeded during day nor night-time at any household. Nature conservation areas are not disturbed
2	Seldom exceeded	15,000 residents are directly affected	Threshold level of noise is seldom exceeded. Fauna in nature conservation areas is slightly disturbed
3	Seldom exceeded	20,000 residents are directly affected	Threshold level of noise is seldom exceeded due to drilling and blasting operations, use of mining equipment or transport near dwellings or residential areas. Fauna in nature conservation areas is slightly disturbed
4	Seldom exceeded	25,000 residents are directly affected	Threshold level of noise is seldom exceeded due to drilling and blasting operations, use of mining equipment or transport near dwellings or residential areas. Fauna in nature conservation areas is slightly disturbed
5	Recurrently exceeded	30,000	Threshold level of noise is recurrently exceeded due to drilling and blasting operations. Fauna in nature conservation areas is heavily disturbed
6	Recurrently exceeded	35,000	Threshold level of noise is recurrently exceeded due to drilling and blasting operations. Fauna in nature conservation areas is heavily disturbed
7	Recurrently exceeded	30,000	Threshold level of noise is recurrently exceeded due to drilling and blasting operations. Fauna in nature conservation areas is heavily disturbed

and watering systems were applied at separation (Table 6).

The dust evaluation matrix contains threshold of noise and number of residents (Table 6).

## Results

Results of evaluation of oil shale mining environmental impact with total impact points are shown in Table 7 and Fig. 7. The strongest total impact was until 1991. Backfilling helps to reduce the impact on the environment mainly with reducing the impact of waste rock, but also the impact of landscape, resource usage and surface water. Increasing the capacity of oil shale mining, the environmental impact also increases.

## Landscape

According to the matrix and the model of mining technologies, impact points were applied for every mining area (Table 8).

The main solution for lowering mining impact on the landscape is reclaiming and backfilling. Another alternative to backfilling is full seam underground extraction.

## Resources

According to the matrix, the impact points were applied for each variant. Backfilling helps to improve resource usage (Table 9).

## Waste

Impact points of waste rock contains produced amount of waste rock and amount of organics in the waste rock heaps (Table 10).

## Water

Collected and analysed data from observation net give the result how to evaluate the impact for groundwater and surface water. The present work has examined the impact of drawdown cone by analogy method (relationship between existing extraction of the average drawdown cone radius) (Fig. 8).

The monitoring of chemical composition of groundwater is carried out in the boreholes of national company monitoring networks. The changes in chemical composition of groundwater in boreholes or surface water monitoring sites are presented in Table 11.

The impact on water increases with mining production increase, and backfilling technology helps to reduce impact on water (Table 12).

When the annual oil shale production was about 25 million tonnes (variant no. 5), a large amount of groundwater was pumped out and the quality of the groundwater of the Ordovician groundwater body in the area of Ida-Viru oil shale basin deteriorated. From the above body of groundwater, the abstraction of water was the biggest and it was most intensively influenced by the mines. After the 1990s, the pollution load began to decrease. The reason for this was smaller amount of precipitation on the one hand, but mainly it was due



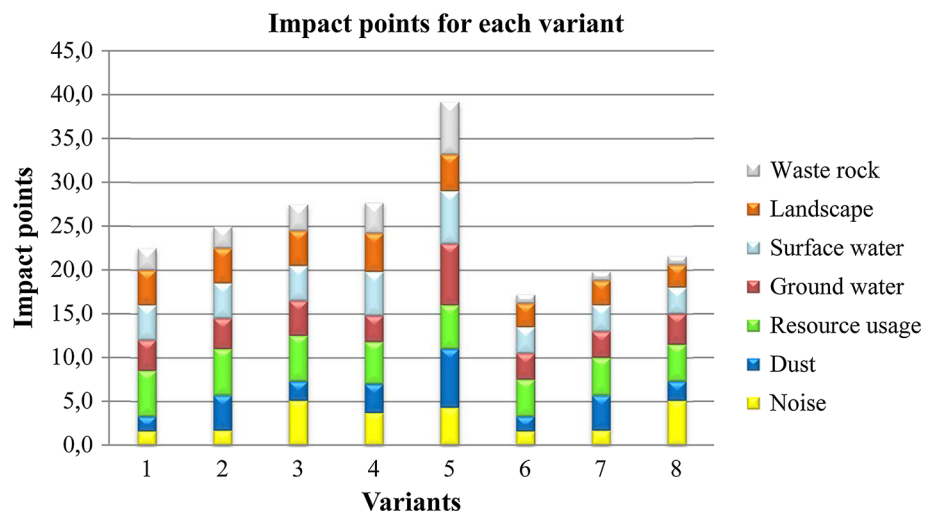
**Table 6** Matrix of mining-related dust evaluation

Impact points	Threshold of dust	Number of residents	Remark
1	Not exceeded	No residents	Threshold level of dust is exceeded during the day nor night-time at any household. Nature conservation areas are not disturbed
2	Seldom exceeded	5000 residents are directly affected	Threshold level of dust is seldom exceeded. Fauna in nature conservation areas is slightly disturbed
3	Seldom exceeded	10,000 residents are directly affected	Threshold level of dust is seldom exceeded due to drilling and blasting operations, use of mining equipment or transport near dwellings or residential areas. Fauna in nature conservation areas is slightly disturbed
4	Seldom exceeded	15,000 residents are directly affected	Threshold level of dust is seldom exceeded due to drilling and blasting operations, use of mining equipment or transport near dwellings or residential areas. Fauna in nature conservation areas is slightly disturbed
5	Critically exceeded	20,000	Threshold level of dust is critically exceeded due to drilling and blasting operations. Fauna in nature conservation areas is heavily disturbed
6	Critically exceeded	25,000	Threshold level of dust is critically exceeded due to drilling and blasting operations. Fauna in nature conservation areas is heavily disturbed
7	Critically exceeded	30,000	Threshold level of dust is critically exceeded due to drilling and blasting operations. Fauna in nature conservation areas is heavily disturbed

**Table 7** Impact points of the studied mining scenarios

Variants Impact field	Mining without backfilling					Mining with backfilling		
	20 Mt/y 1	24 Mt/y 2	28 Mt/y 3	2008 y 4	until 1991 y 5	20 Mt/y 6	24 Mt/y 7	28 Mt/y 8
Waste rock	2.5	2.5	3.0	3.5	6.0	1.0	1.0	1.0
Landscape	4.0	4.0	4.0	4.4	4.2	2.7	2.8	2.6
Surface water	4.0	4.0	4.0	5.0	6.0	3.0	3.0	3.0
Ground water	3.5	3.5	4.0	3.0	7.0	3.0	3.0	3.5
Resource usage	5.2	5.3	5.2	4.8	5.0	4.2	4.3	4.2
Dust	1.7	4.0	2.2	3.3	6.7	1.7	4.0	2.2
Noise	1.6	1.7	5.1	3.7	4.3	1.6	1.7	5.1
Total	22.5	25.0	27.5	27.7	39.2	17.2	19.8	21.6

**Fig. 7** Impact points for each studied variant



**Table 8** Mining areas and mining impact on the landscape

Mining area Variant	Area, sq. km					Impact points							
	5	4	1	2	3	5	4	1	2	3	6	7	8
Underground mines													
Mine 2	11	11	11	11	11	5	5	5	5	5	5	5	5
Mine 4	11	11	11	11	11	5	5	5	5	5	5	5	5
Ahtme II mine	0	0	0	2	2				3	3	0	1	1
Ahtme mine	29	33	33	33	33	4	4	4	4	4	4	4	4
Aidu South mine	0	0	0	0	3					2	0	0	1
Estonia mine	37	75	116	116	120	3	3	3	3	3	1	1	1
Estonia South mine	0	0	0	8	12				3	3	0	1	1
Kiviõli mine	29	29	28	28	28	4	4	4	4	4	4	4	4
Kohtla mine	13	18	19	20	20	4	4	4	4	4	4	4	4
Kukruse mine	12	12	12	12	12	6	6	6	6	6	6	6	6
Käva 1 mine	3	3	3	3	3	7	7	7	7	7	7	7	7
Käva 2 mine	14	14	14	14	14	4	4	4	4	4	4	4	4
Narva II South mine	0	0	0	0	4					4	0	0	1
Ojamaa mine	0	0	12	12	12			2	2	2	1	1	1
Sompa mine	23	26	26	26	3	4	4	4	4	4	4	4	4
Sompa II mine					3	2	2	2	2	2	1	1	1
Tammiku mine	0	0	0	34	34	4	4	4	4	4	4	4	4
Ubja mine	1	1	1	1	1	7	7	7	7	7	7	7	7
Uus-Kiviõli mine	0	0	12	12	12			2	2	2	1	1	1
Viivikonna mine	1	1	1	1	1	4	4	4	4	4	4	4	4
Viru mine	17	29	31	31	31	3	3	3	3	3	3	3	3
Surface mines													
Aidu II open cast	0	0	0	4	4				2	2	0	2	2
Aidu open cast	15	23	23	23	23	5	5	5	5	5	5	5	5
Kohtla open cast	3	4	4	4	4	6	6	6	6	6	6	6	6
Kohtla-Vanaküla open cast	1	1	3	3	3	2	2	2	2	2	2	2	2
Küttejõu open cast	1	1	1	1	1	7	7	7	7	7	7	7	7
Narva open cast	22	30	46	46	47	5	5	5	5	5	2	2	2
Põhja-Kiviõli II open cast	0	0	7	7	7			2	2	2	2	2	2
Põhja-Kiviõli open cast	0	3	1	1	1		2	2	2	2	2	2	2
Sirgala open cast	29	38	50	50	50	5	5	5	5	5	2	2	2
Ubja open cast	0	0	1	1	1			2	2	2	2	2	2
Vanamõisa open cast	0	0	0	0	0	6	6	6	6	6	6	6	6
Tammiku Kose open cast					0					2	0	0	2
Viivikonna open cast	33	38	41	41	41	5	5	5	5	5	2	2	2
Underground mines	202	266	332	375	372	4.0	3.8	3.6	3.6	3.6	2.8	2.9	2.7
Open-cast mines	104	137	178	182	183	5.0	5.0	4.8	4.8	4.8	2.5	2.5	2.5
Total	306	402	510	557	555	4.4	4.2	4.0	4.0	4.0	2.7	2.8	2.6

to decrease in the intensity of agricultural activities and use of fertilizers. The decrease in pollution load was favoured also by launching of several new sewage plants and renovating of existing ones in the past decade.

In case of the annual mining volumes of oil shale up to 20 million tonnes and above that (up to 28 million tonnes), the groundwater quality indicators must be monitored and

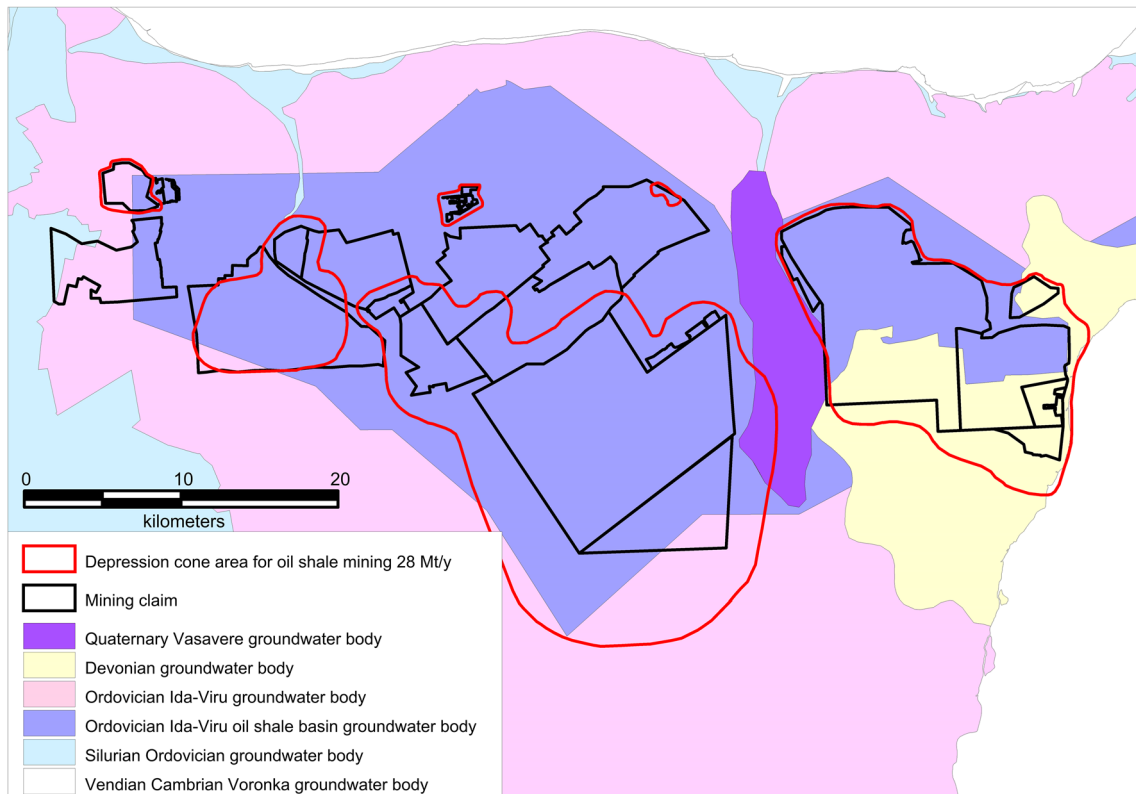
improved; the latter will largely influence also the quality characteristics of surface water. Settling basins are needed for the surface water. The volumes of oil shale extraction should not considerably influence the groundwater quality. It is important to specify that there are no other sources of groundwater contamination (e.g. agricultural contamination) (see Table 12).

**Table 9** Impact points of oil shale resource usage

Variant	1	2	3	4	5	6	7	8
Production, Mt/y	20	24	28	13.7	15...33	20	24	28
Resource use, Mt/y	29.1	35	41	17.4	24...45	–	–	–
Total losses, %	31	31	33	21	5...45	–	–	–
Resource index	1.1	1.1	1.1	1.1	1.2	–	–	–
Impact points	5.2	5.3	5.2	4.8	5	4.2	4.3	4.2

**Table 10** Oil shale waste rock impact points

Variant	1	2	3	4	5	6	7	8
Amount of waste rock impact points	3	3	4	3	5	1	1	1
Organics in waste rock impact points	2	2	2	4	7	1	1	1
Waste rock impact points	2.5	2.5	3	3.5	6	1	1	1



**Fig. 8** Groundwater bodies and depression cone for oil shale mining of 28 Mt/y (variant 3)

**Noise and dust**

Table 13 shows that the dust impact in case of variant 2 for the surrounding territories is smaller than that in case of variant 4, because the mining activity is moving further from settlements.

In variant 4, the surface mines have more weight than other variants when mining activities are moving to underground mines. In variant 4, most of the noise was caused by drilling–blasting, which were closer to settlements.

Impact of dust in impact points is shown in Table 14.

**Table 11** Example table of chemical composition of groundwater or surface water to evaluate impact

	Boreholes <sup>a</sup>				Impurity	Unit	Threshold limit value in groundwater	Aquifer no, in which threshold limit value is applied
	335	335-A	5028	19,606				
SO <sub>4</sub>	-	+	+	-	Monobasic phenolic	µg/l	1	5, 6, 16
PH	+	+	+	+	Nafta spin-off	µg/l	20	5, 6, 7, 8, 9, 10, 11, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25
PHT	+	+	+	-	Benzene	µg/l	1	5, 6, 7, 8, 9, 10, 11, 16
Nafta spin-off	-	-	+	-	Sum of PAH	µg/l	0.1	5, 6, 7, 8, 9, 10, 11, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25
Benzene	+	+	+	+	SO <sub>4</sub>	mg/l	250	6
Monobasic phenolic	-	-	-	-				
Sum of PAH	+	+	+	+				
	Boreholes <sup>b</sup>				Repugnant substance	Threshold limit value of groundwater quality		
	335	335-A	5028	19,606		Min, µg/l	Max, µg/l	
Benzene	*	*	+	*	Benzene	0.2	5	
Monobasic phenolic	*	*	*	*	Monobasic phenolic	1	100	
Sum of PAH	+	+	+	+	Sum of PAH	0.2	10	

<sup>a</sup> Aquifer quality is acceptable, when pH 6–9 and PHT ≤ 5 mg/l O<sub>2</sub>. +: Correspond to limit value, -: Do not correspond to limit value

<sup>b</sup> +: Satisfied quality of groundwater, -: Groundwater is polluted, \*: Groundwater is neither polluted nor good

**Table 12** Impact points of evaluation of groundwater and surface water in the mining area

Variant	1	2	3	4	5	6	7	8
Groundwater impact points	3.5	3.5	4	3	7	3	3	3.5
Depression cone area	4	4	5	3	7	4	4	5
Groundwater chemistry	3	3	3	3	7	2	2	2
Surface water impact points	4	4	4	5	6	3	3	3
Pumping	5	5	5	7	5	4	4	4
Surface water chemistry	3	3	3	3	7	2	2	2

### Discussion

Creating the criteria of environmental impact for oil shale mining was important for decisions about increasing the yearly production in the future.

The advantage of this assessment was the result of environmental impact evaluation, which has not been made before. The disadvantage of this assessment was the fewness of evaluated data.

Strongest impact on the landscape has been underground mining in shallow areas, because of the unstable or

quasistable areas (Table 8). Previous mines, both surface and underground mines had stronger influence. Early surface mines did not level the spoils like today. Early underground mines were located under weaker and shallower covering rock, and this has caused collapses and weak landscape in corresponding zone. In these conditions, surface mining or mining with backfilling or longwall mining is preferred. In every depth, backfilling gives the lowest impact on the landscape because of the resulting stable land and the absence of mining waste deposits. In the middle zone, both by depth and period, different sizes of the pillars and longwall mining with variations have been used. This caused stronger impact by these mines than today's or future mines.

Oil shale mining depth is increasing in Estonia. Mining with backfilling helps to reduce losses and secures the sustainability. Sustainable and environmentally acceptable oil shale mining secures reserves for the future.

Oil shale waste rock from separation process to waste rock heaps dumping amount is related to the fact whether the backfilling is used in oil shale mines or not and how much waste rock can be used as aggregate for building materials.

In order to reduce the chemical indicators of surface water and groundwater, which exceeded the limit values so

**Table 13** Impact points of mining noise

Variant	1	2	3	4	5	6	7	8
Significance	0.143	0.143	0.429	0.286	0.429	0.143	0.143	0.429
Drilling–blasting	5	6	6	7	4	5	6	6
Machinery	1	1	1	1	1	1	1	1
Railroad transport	5	5	5	5	5	5	5	5
Total	1.6	1.7	5.1	3.7	4.3	1.6	1.7	5.1

**Table 14** Impact points of mining dust

Variant	1	2	3	4	5	6	7	8
Significance	0.167	0.333	0.167	0.333	0.667	0.167	0.333	0.167
Drilling–blasting	5	6	6	5	5	5	6	6
Machinery	1	1	1	1	1	1	1	1
Railroad transport	4	5	6	4	4	4	5	6
Total	1.7	4.0	2.2	3.3	6.7	1.7	4.0	2.2

that these would meet the established requirements, these must be continuously monitored, and to make sure that the settling basins operate with optimal load and under the preassigned conditions. It must be strictly followed that from this time forward unwarranted amounts of phenols and oil compounds do not go into surface water. It is also favourable for the quality of groundwater when the abandoned mines become filled with water. Under such conditions, the content of SO<sub>4</sub> in groundwater decreases in connection with stabilisation of groundwater level.

Moving to underground with mining processes could reduce noise and dust emission.

**Conclusion**

Environmental impact of oil shale mining in Estonia with and without backfilling for 20, 24 and 28 Mt/y production was evaluated for the future and compared with the past. Ground stability, landscape properties, mining waste management, usage of resources and mining losses, water management with water quality and depression cones, noise and dust were analysed on 7-point impact point’s scale. As a result of this study, criteria for estimating environmental impact of oil shale mining were created. The 7-point impact point scale improved itself as handy method and detailed enough. This method has not been used before.

The strongest total impact of 39,2 impact points was until 1991 when the mining capacity of oil shale was high and no strict mining laws were validated or followed. Backfilling helps to reduce the impact on the environment about 5 impact points mainly with reducing the impact of waste rock, but also the impact of landscape, resource usage and surface water. Impact of waste

rock reduces as it will be used in backfilling mixture and smaller amount of waste rock will be left over. The surface will be more stable as the backfilled underground supports the ground. Oil shale resource usage will be more effective as the pillars can be mined out. With increasing capacity of oil shale mining, the environmental impact also increases.

**Acknowledgments** This research is part of the project B36 Extraction and processing of rock with selective methods—mi.ttu.ee/separation, SA Archimedes European Regional Development Fund Project No. 3.2.0501.11-0025 (2012–2015) “Sustainable and environmentally acceptable oil shale mining”, Estonian Science Foundation Project No. ETF9018 “Mine collapses in NE Estonia—detection, identification and causes” and Estonian Science Foundation Project No. ETF8999 “Tectonics of the continental and offshore territory of Estonia and its structural evolution in Proterozoic and Phanerozoic”.

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