

# ENVIRONMENTAL IMPACT ASSESSMENT FOR ESTONIAN OIL SHALE MINING SYSTEMS

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## ABSTRACT

The Estonian economy is strongly based on oil shale as a mined resource, and various quality of oil shale are supplied to power plants and chemical industry. However, the environmental impacts associated with the preparation and production of oil shale. The different mining methods used for oil shale extraction and accompanied development processes have various environmental impacts. In Estonian mining industry practice rarely takes into consideration necessary, essential details causing environmental impacts. Emission per one ton of excavated oil shale from “Estonia” and “Viru” mines and their share in climate change and acidification are presented. Take into account impact category includes ground surface subsidence, land use, mine water pollution.

## 1. INTRODUCTION

During the 90 years one billion tone of oil shale has been mined at Estonian oil shale deposit. The area of the Estonian oil shale deposit approximately 400 km<sup>2</sup>, which located in the north-eastern part of the country. About 72% of the oil shale extracted is used for electricity generation, 22% for chemical industry (shale oil from mines 28 %, opencast - 9%) and 6% for heat generation (*Gavrilova O. et al. project 2005*). The main company Eesti Põlevkivi – company of oil shale production and distribution include two operational mines (“Estonia” and “Viru”) and two operational open casts (“Narva” and “Aidu”). The annual extraction of oil shale is 10 -14 thousand tones, with 47% extracted by opencast methods and 53% by underground methods. The losses in underground mining are about 20-30% (room-and-pillars method) and 5 - 10% by opencast mining. Opencast mining is carried out at depths of 5-20 m and underground mining 20-70 m.

Nowadays in “Estonia” mine new technology is based on a blasting method applying emulsion explosives instead of packaged ones, change from 2.0 m to 4.0 m boreholes and on a new large-hole undercutting method using modern machines. Loading and transportation of blasted mined rock is carried out by powerful LHD machines with diesel drive like TORO and WAGNER. The average productivity of such technology is 1500-2300 m<sup>3</sup> of rock mass per day. (*Nikitin O & Sabanov S*). This is one of the reasons why emission of carbon dioxide from “Viru” mine mach less on account of uses old technology based on old machinery working by electrical power.

The functional unit of the system under investigation is 1 ton of oil shale. The necessary tool identified all the technological chains of mines under investigation.

## 2. GOAL OF THE STUDY AND INVENTORY ANALYSIS

The goal of the study is to assess of the environmental impact of the Estonian oil shale mining system. The results of the study will be used for new mines planning in according with environmental performances and supplied economic values.

Inventory analysis involves data collection and description of unit processes for calculation procedures. Data collection includes all emissions associated with the oil shale excavation processes. Descriptive information of unit processes is necessary tool for evaluation operation option and environmental impact. Description of unit processes presents a general overview of in underground mining, according to what technology is applied and what equipment is used in excavation processes.

### 2.1. Description of unit processes.

New machinery and modern technology in "Estonia" mine should guarantee greater extraction of oil shale than in "Viru" mine, using old machinery. On the other hand old machinery work only on an electricity and do not emissions from diesel combustion, therefore calculated emissions attributed to power generation. Necessary data for emissions evaluation from supply unit of machine and consumption type are presented (Table 1).

Drilling - for drilling face and roof use electricity and diesel to produce maneuvers ("Estonia" mine).

Blasting - emulsion explosive injected into drilled boreholes by charging module. In "Viru" mine cartridge explosives charged by hand.  $\text{NH}_4\text{NO}_3$  - the production of ammonium nitrate from ammonia and nitric acid.

Loading - loading and transportation of blasted mined rock by powerful LHD machines with diesel drive and placed on chain conveyor. The chain conveyor takes the rock to the collection drift belt conveyor.

Transportation - the panel drift belt conveyor transport rock mass to the enrichment factory. In "Viru" mine transportation made by cars to the bunker and then to enrichment.

Enrichment - in the enrichment factory rock mass crushed, sieved and treatment of rock in the medium of heavy suspension to separate the oil shale fraction suitable for power plants and chemical industry. Heat energy - production shale oil in the boiler-house.

Table 1. The primary supply unit for machine and consumption type

| Processes                             | Machine and consumption type | Supply                    | Supply unit |
|---------------------------------------|------------------------------|---------------------------|-------------|
| Drilling                              | Atlas Copco                  | Diesel fuel & electricity | l/day, KWh  |
|                                       | Smag                         | Diesel fuel & electricity | l/day, KWh  |
|                                       | BUA -3 C                     | Electricity               | KWh         |
| Blasting                              | Charging module              | Diesel fuel               | l/day       |
|                                       | Explosives                   | $\text{NH}_4\text{NO}_3$  | kg/day      |
| Loading                               | Wagner                       | Diesel fuel               | l/day       |
|                                       | Toro 400 D                   | Diesel fuel               | l/day       |
| Transportation                        | Conveyor belt                | Electricity               | KWh         |
|                                       | Railway track                | Electricity               | KWh         |
| Enrichment                            | Crusher, sieve               | Electricity               | KWh         |
| Loading to storage for transportation | Wheel loader                 | Diesel fuel               | l/day       |
| Heat energy                           | Boiler-House                 | Shale oil                 | l/day       |

Selected emissions per 1 ton of excavated oil shale from "Viru" and "Estonia" mines according to environmental impact assessment (Table 2).

Table 2. Emissions per 1 ton of excavated oil shale

| Emission to air                       | VIRU     | ESTONIA  |
|---------------------------------------|----------|----------|
| Carbon dioxide, CO <sub>2</sub> , kg  | 2.8      | 3.6      |
| Metal, CU, air, kg                    | 1.15E-09 | 1.17E-09 |
| Metal, Ni, air                        | 1.06E-10 | 1.12E-10 |
| Nitrogen oxides, NO <sub>x</sub> , kg | 0.0047   | 0.0034   |
| Metal, Pb, air, kg                    | 5.12E-09 | 5.25E-09 |
| Sulfur dioxide, SO <sub>2</sub> , kg  | 0.026    | 0.0096   |
| Emission to water                     | VIRU     | ESTONIA  |
| Total nitrogen, N, kg                 | 1.27E-05 | 0.018    |
| Total phosphorus, P, kg               | 2.47E-07 | 0.0003   |
| SO <sub>4</sub> , water, kg           | 0.0047   | 4.75     |

### 3. THE METHODOLOGY

Appropriate impact categories (e.g., climate change and acidification) were selected on the basis of the existing inventory data and of the general knowledge about cause-effect relationships. After that the inventory data were assigned into the impact categories (classification). In the characterization, the chosen characterization factors enable an aggregation of the emissions within each impact category. The emission values are converted into impact category indicator results by multiplying the emission values by the corresponding characterization factors. In order to produce scientifically based characterization results, the determination of characterization factors within a certain impact category is a key issue ([www.energia.ee/OSELCA](http://www.energia.ee/OSELCA)).

#### 3.1 Classification and descriptions of impact categories

The following impact categories and environmental interventions causing the effects of the impact categories were identified:

- 1) climate change (CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>),
- 2) acidification (SO<sub>2</sub>, NO<sub>x</sub> (expressed as NO<sub>2</sub>), NH<sub>3</sub>)

The term "climate change" describes a range of impacts, which are caused by the so-called "greenhouse gases" contributing to global warming. Greenhouse gas emissions (CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>) are converted to CO<sub>2</sub> equivalency figures by multiplying emissions by their global warming potential (GWP) factors. Thus, characterization for climate change corresponds to the same proceedings used in national greenhouse gas inventories.

Acidification refers to the wet or dry deposition of acidic substance from anthropogenic origin on the earth's surface and is commonly called acid rain, but also includes acid snow and acid fog. Acid rain is able to mobilize metals and other acid soluble compounds from the soils. The acids dissolve aluminum and other metals from soils to the level at which they become toxic to plants and to aquatic organisms. Acidic rain dissolves cement and minerals in the build environment ([www.energia.ee/OSELCA](http://www.energia.ee/OSELCA)).

### 3.2 Characterization

The characterization factors change the values of interventions into the commensurable unit within the impact category so that the values of different interventions can be added together. The unit varies impact by impact depending on the chosen indicator for measuring the effects. Climate change emissions are converted to CO<sub>2</sub> equivalency (Table 3) ([www.energia.ee/OSELCA](http://www.energia.ee/OSELCA)).

Table 3. Characterization factors for climate change.

| Impact category | Emission         | Unit                   | Site-generic |
|-----------------|------------------|------------------------|--------------|
| Climate change  | CO <sub>2</sub>  | kg CO <sub>2</sub> /kg | 1            |
|                 | N <sub>2</sub> O |                        | 310          |
|                 | CH <sub>4</sub>  |                        | 21           |

Different acidifying emissions were aggregated by characterization factors, which are derived from the results of European air quality and transport model (EMEP 1998) and critical loads determined over Europe (Hettelingh et al. 2004). The critical load means that harmful effects will occur if the deposition of acidifying emissions exceeds a certain limit (Table 4).

Table 4. Characterization factors and reference value for acidification.

| Impact category | Emission        | Unit  | Factors for Estonia |
|-----------------|-----------------|-------|---------------------|
| Acidification   | SO <sub>2</sub> | eq/kg | 0.369               |
|                 | NO <sub>2</sub> |       | 0.194               |
|                 | NH <sub>3</sub> |       | 0.405               |

## 4. RESULTS AND DISCUSSION

### 4.1. Climate change

Investigation showed in "Viru" mine climate change indicator results much less than "Estonia" mine. The CO<sub>2</sub> emissions made 99.4 % from total indicators, while CH<sub>4</sub> and N<sub>2</sub>O have rendered insignificant influence (Figure 1).

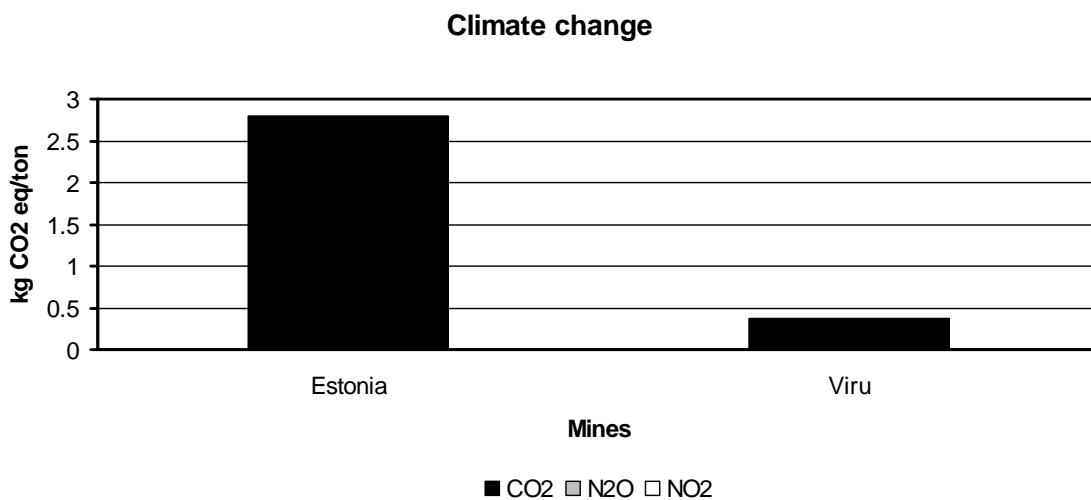


Figure 1. Contributions of different emissions in mining process to climate change.

Mining play minor role on climate change in comparison with production of auxiliary material and transportation oil shale to customers (Figure 2).

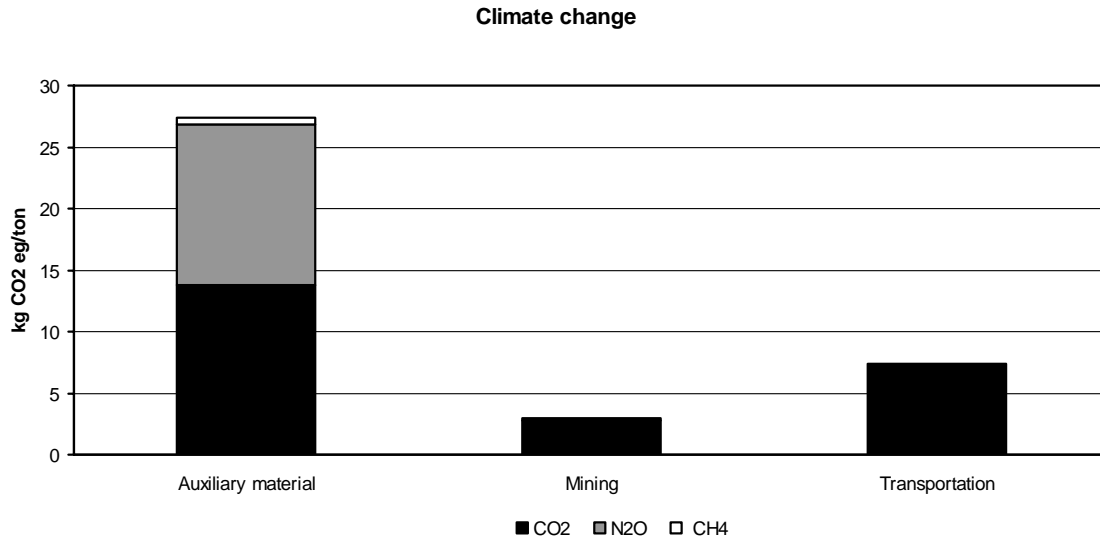


Figure 2. Contributions of different emissions in processes to climate change.

## 4.2 Acidification

In "Viru" mine acidification tree time more, that from "Estonia" mine. The main contributor is SO<sub>2</sub>. The importance of other emissions is insignificant (Figure 3).

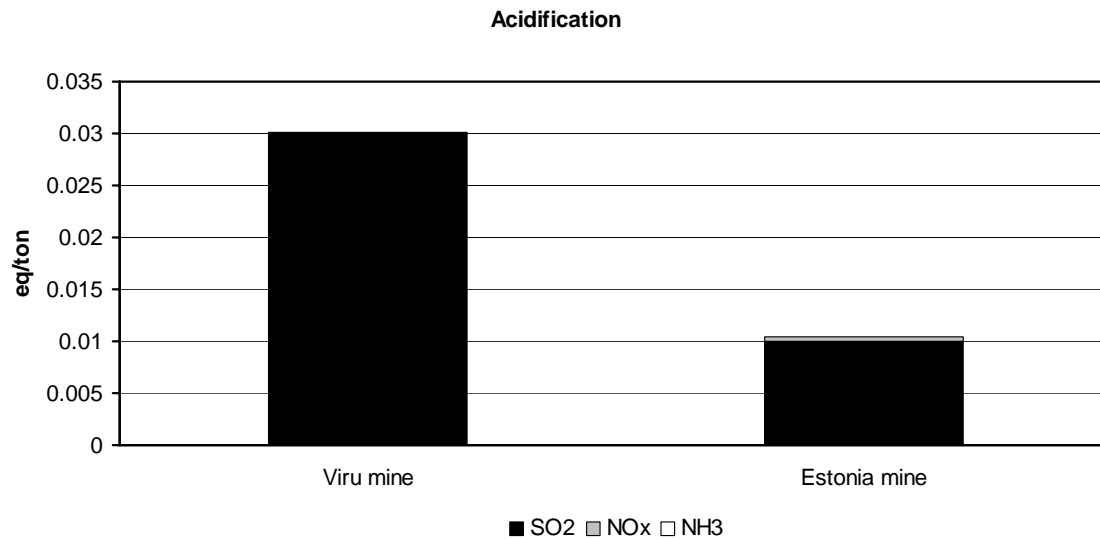


Figure 3. Contributions of different emissions in mining process to acidification.

The result showed that mining causes less acidifying emissions compared with production of auxiliary material and transportation of oil shale to customers. Also in case

of acidification the main contributor in mining production is  $\text{SO}_2$ , while in transportation  $\text{SO}_2$  not so high level, as  $\text{NO}_x$  (Figure 4).

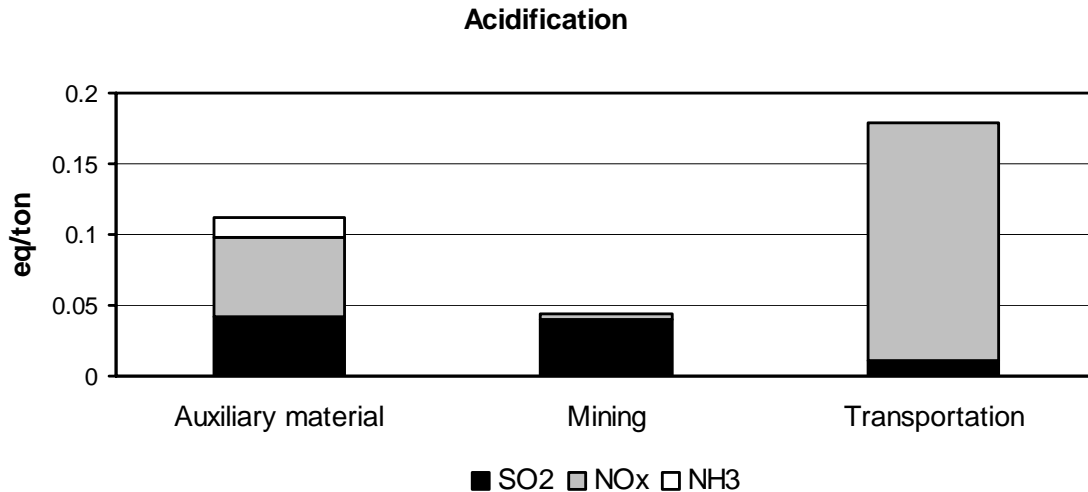


Figure 4. Contributions of different emissions in processes to acidification.

### 4.3 Ground surface subsidence and land use

It has become apparent that the processes in overburden rocks and pillars have caused unfavorable environmental side effects accompanied by significant subsidence of the ground surface. Ground surface subsidence causes soil erosion and flooding, swamp formation, agricultural damage, deforestation, changes in landscape, ground water level decreasing and the formation unstable cavities. It is a large number of technical, economical, ecological and juridical problems.

The structure of the productive oil shale bed makes the rock difficult to break from the total massive. This is also one reason why long wall (shearer) mining has been shortly used. Second reason of long wall mining – inevitable subsidence. Nowadays underground oil shale production is obtained by room-and-pillar method with blasting. The commercial oil shale bed and immediate roof consist of oil shale and limestone seams. The main roof consists of carbonate rocks of various thicknesses. The characteristics of various oil shale and limestone seams are quite different. The strength of the rocks increases in the southward direction. The compressive strength of oil shale is 20-40 MPa and that of limestone is 40-80 MPa. The volume density is 1.5-1.8 Mg/m<sup>3</sup> and 2.2-2.6 Mg/m<sup>3</sup>, respectively. For this reason pillars stability is difficult to prognosis. Ground surface subsidence result of pillars collapse. Depth of subsidence depends on extracted seam thickness. The first spontaneous collapse of pillars and surface subsidence in an Estonian oil shale mine took place in 1964. Up to the present, 73 collapses have been recorded. (*Pastarus J.-R. & Sabanov S.*)

The commercially important oil shale bed is situated in the north-eastern part of Estonia. It stretches from west to east for 200 km, and from north to south for 30 km (Figure 1). The oil shale bed lays in the form of a flat bed having a small inclination in southern direction. The total volume of waste from oil shale mining is 180 million tones and it

covers 188 ha from mines and 150 ha from open casts in con-shaped dump. The volume of waste on used landfills on “Estonia” mine 70 million tones, on “Viru” mine 35 million tones. From the area as large as 220 km<sup>2</sup> oil shale has been mined by underground method. 61% of the total oil shale has been extracted from underground mines. Per tone of extracted oil shale half ton waste is generated in the process of oil shale enrichment. Wastes destroyed agricultural land cover and ecosystems.

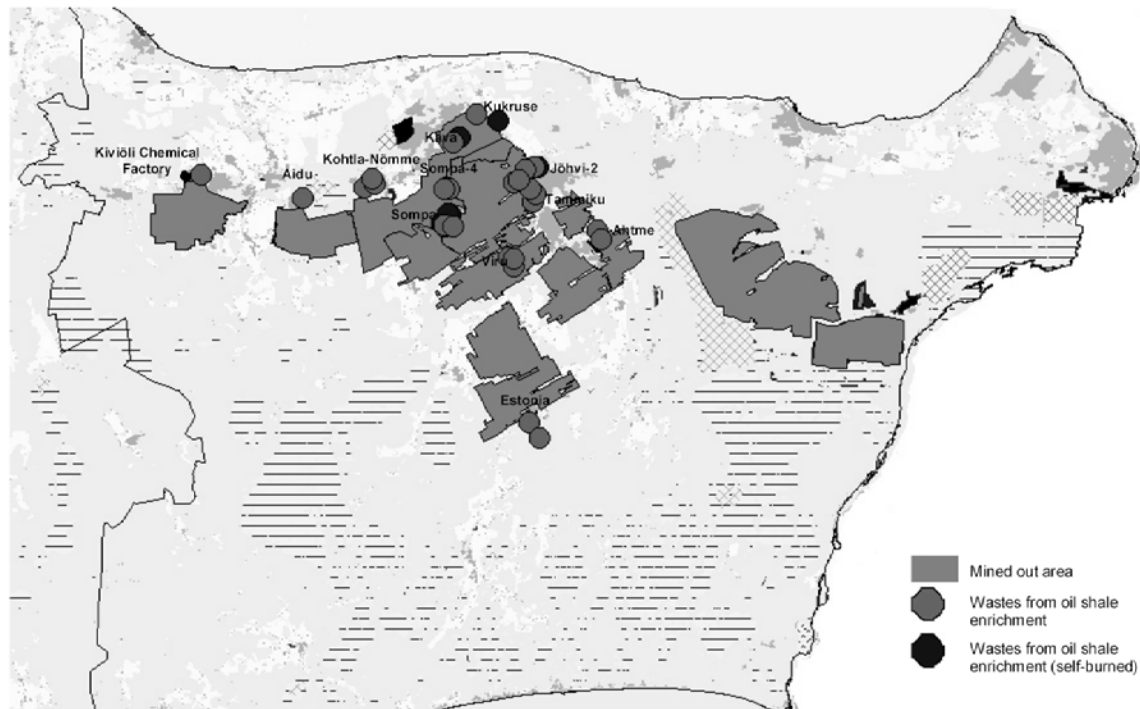


Figure 1. Mined out area and wastes from oil shale enrichment. (Sõrlie J.-E. et al., 2004; Basic map)

#### 4.4 Mine water pollution

Annual water outlet of the mining enterprises of Eesti Põlevkivi Ltd. amounts to 200 - 240 million m<sup>3</sup>. The share of pumped out water from “Estonia” mine made 63 million m<sup>3</sup> and from “Viru” mine is 19 million m<sup>3</sup>. On this reason the depth of the sinkhole reaches 70 m, with impact radius 5-10 km. Mining waters don't have major impact on the composition of natural waters: Fe, NH<sub>4</sub><sup>+</sup>, BHT20 levels are decreased, SO<sub>4</sub><sup>-</sup>, Cl<sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, K<sup>+</sup>, Na<sup>+</sup> levels are increased, the amount of heavy metal compound mining waters is lower than the natural level of North-East Estonia ([www.ep.ee](http://www.ep.ee)).

### 5. CONCLUSION

Underground mining causes smaller impacts on climatic changes and acidification than production of auxiliary materials and transportation of oil shale to customers. This method assesses environmental impact of excavation processes and finds better way of doing proposed project. The results of the study will be used for new mines planning in according with environmental performances and supplied economic values.

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