Sustainable Mining Conditions in Estonia

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Abstract - Sustainable mining conditions depend on definitions, technological level and administrative system. The main tools to analyse these conditions is geometrical, quality, numerical and economic analyses. As a result, most of the processes are evaluated and concluded for following decision making. The main directions in Estonian mining are selective mining, selective crushing, quality management of the mineral, backfilling and long- and shortwall mining.

I. INTRODUCTION

The set of sustainable mining conditions should be bridge between mining operations and those who are influenced. Sustainable mining is technically using the best available mining technology (BAMT) for mineral production. In different conditions and in different location the best available technology would be different. The definition of best available technology depends on several conditions and is changing between mining locations and time periods. Sustainable development is one of a range of ideas about how humans should best interact with each other and the biosphere. [2]

In Estonia the sustainable mining questions have been raised mainly about those mineral resources that participate in international competition. These minerals are oil shale, technological dolostone, technological limestone and peat. Potentially problematic minerals are granite, phosphate rock and dicytonema shale (graptolite argillite). As well the mining location influencing people are problematic, in spite of the mineral mined.

During the mining history attitude to the sustainability has changed. The main influencers have been competition, economic situation, good will and the level of mining engineers. Competition and economy force mining economically. In most cases economical mining is controversial to the sustainable mining. Economics forces also engineers to concentrate to the production and less to the development. [47], [48] From here the question arises, what criteria influences sustainability, what is the theoretical possibility for sustainable mining and in what extent does it differ from practice.

The main difference of the mining conditions from other disciplines is that mining conditions are getting worse in time and availability of raw materials is getting more complicated. This problem can be relieved only with help of basic research on the recourse usage.

Estonia is rich on oil shale, construction minerals and peat. The increase of their mining intensity and requirements to the limitations of mining influences and new mining technologies require the basic research that has not been performed during last thirty years in Estonia.

Mineral resources are exploited everywhere in Estonia, also in the sea bottom. Largest in volume are the building materials: sand, gravel, clay and building stone – 57 % of total mass. The second half consists of fuel and technological raw material: oil shale, peat and technological lime- and dolostone. Mineral deposits cover 13 % of the area of Estonia, including 8 % covered with peat and 4 % with oil shale. Phosphate rock, granite and dicytonema shale have become actual or potential mineral resources.

The problems related to mining of the principal resources – oil shale, building material and peat – are generated both in state and local level because of the reason that satisfying solutions do not exist for utilizing natural resources, i.e. mineral, water, land and forest resources. There is a lack of appropriate mining technological solutions, development plans, legislation, as well as know-how.

Mining alters the environment, underground conditions and landscape. Mining-related perturbing factors and changes of property cause public resistance. Various restrictions for mining (environmental restrictions) are created in reaction to this. [24], [25] In the majority of the cases, their argumentation is one-sided, often subjective. As a result, it is not possible to utilize a large proportion of deposits because of environmental restrictions, but also because of expiration of evaluation criteria of the supplies of resources. [17], [22], [23]

On the other hand, Estonia needs its resources – mineral and organic deposits, groundwater and ground support for building. Mining and building are tightly related, particularly in the case of building material resources. Despite this fact, it happens that the domains of mining, building and agriculture often operate without coordination. For instance, buildings for mining or mines are planned in regions that have high potential for agriculture or building. In many cases, the reason is ignorance of spatial and temporal scales of effects of technogenic factors (mobility of soil, water or pollutants). This is magnified by the fact that the spatial-temporal mobility of such factors is non-linear. Part of the problems is caused by miners that do not apply environmentally friendly mining technologies. [37], [38], [39]

The principal mining regions of Estonia are: Lääne-Harju (Vasalemma, Padise, Harku etc. deposits), Ida-Harju (Lasnamäe, Väo, Maarud etc. deposits), Kunda-Rakvere (Toolse, Ulja, Aru etc. deposits) and Ida-Viru (Estonian oil shale deposit, peat deposit of Puhatu and many locations for mining building material). [19], [20] Smallest number of problems is faced in old mining regions, mainly because there
exists the “State plan for utilization of oil shale, 2008-2015”. On the other hand, acceptable mining environment have been developed in old mining regions.

Mining environment is understood as the entity including resources (deposits and groundwater), land (agricultural and housing land), engineering and technology.

Long-term research of TUT Department of Mining and the co-operators have shown that ground and landscapes changed by mining can be of better quality afterwards than before. If reclaiming is planned skillfully, the soil, landforms, forest, water bodies and agricultural land can be more valuable than before mining. [5] All this is the basis for developing acceptable, environmentally friendly mining. Creating acceptable mining requires engineering research both in natural and technogenic environment, e.g. modelling and pilot projects. Such research is voluminous, what is the reason that in Estonia, as well as elsewhere, computer modelling has become the principal tool in solving problems related to all sorts of developments, technologies and effects. [10], [11], [12] The key issue is defining criteria and restrictions that satisfy all the involved parties.

Creating models and estimation criteria requires mining-related expertise, and a database acquired from measurements, experimenting and laboratory testing. [21] For this purpose, the Department of Mining has the relevant laboratories (see http://mi.ttu.ee/laboratory/). Modelling is followed by laboratory and industrial experiments, which require profound know-how. In 2005-2011, the Department of Mining conducted industrial experiments in AS VäoPaas, AS Kiviõli chemical factory, AS PaekivitoodeteTehas, AS Kunda Nordic Tsement and EestiEnergi mining surface and underground mines. The experiments included e.g. chronometry of technological productivity, geometric and geological measurements, and measurements of rock quality. [13] The related pilot experiments, ensuring road stability, were conducted in the autumn 2009 at the Kukruse overpass of the Tallinn-Narva main road. [4]

The parties that compose mining plans, development plans and estimations of environmental effects (TUT Department of Mining, mining engineering offices, geological institutions) have acquired planning and modelling software for various purposes, which causes some problems:

1. The geological database, the first parts of which date back from over 50 years, requires skillful treatment: data exist in several geodetic coordinate systems and includes partly obsolete stratigraphic terminology. Unfitting coordinate systems disturb the usage of cross-use of spatial data in various state geoinformation databases (digital maps, border files, land registers, building registers, databases of technological networks of enterprises, etc.). This creates further problems related to mined areas.

2. The main proportion of environmental restrictions, which have to be taken into account in mining and building, are speculative and not based on real measurements. Usually the restrictions are two-dimensional and do not take into account the structures of the geological environment. Such vagueness does not support precise engineering calculations or modelling.

3. Ground modelling systems that are designed in developed mining countries are principally meant for deep deposits. However, in Estonia there are blanket deposits, which cause wider environmental effect of mining. Because of that reason, imported systems have to be adapted. Modelling and planning software adapted for Estonian blanket deposits can be recommended for use in other analogical mining conditions elsewhere, e.g. in Ukraine or Jordan.

Based on requirements by economy and the state, the main criteria are diminishing both the loss of resources and the environmental effect of mining. The main targets in the oil shale deposit are new, planned mines: Uus-Kiviõli, Narva, Kuremäe (in the Puhatu region), Sonda (partly in the Lääne-Viru region). The principal building material deposit targets are all deposits in northern Harjumaa and Raplamaa: Nabal, Harku, Maardu etc.

The biggest section in mineral process in which saving and effectiveness could be achieved is the mining sector. It includes social and environmental restrictions in deposits, losses in pillars and separation of products and waste rock. [46] Losses are closely related to backfilling and waste rock usage. Much smaller sections include (in case of oil shale usage) production of oil, electricity and chemicals in which most of the research and development is performed today. Efficiency of oil shale usage depends mainly on mining technology. Current urgent topics for investigating, testing and developing of oil shale mining related questions are backfilling, mechanical extracting of shale, fine separation, selective separation and optimised drilling and blasting.

Estonian oil shale mining industry with its 90 years of history has been a test polygon for equipment manufacturers, geologists and mining engineers from Germany, Soviet Union, Finland and Sweden.

Estonia as active mining waste producer has been good area for collecting and analysing mining waste data. [3] In reality there are no real tools, method or solutions for solving mining waste handling requirements. Recent studies in oil shale and limestone production line have shown that investigating waste balance and handling techniques requires complex study beginning from geological investigation, going through opening mining fields, preparing process, overburden removal and auxiliary processes, extracting mineral resource, processing, separating, transporting and depositing. [29]. All these processes have far more influence to the waste percentage and properties than end user processes. The minerals that are being studied are oil shale, limestone, dolostone, granite, dictyonema shale and phosphate rock. Since international projects are being involved, other minerals from surrounding countries are being compared as well. The study includes geological and mining technological modelling, collecting waste samples, testing their properties and testing their modifications. The purpose is to find solutions for decreasing waste amount and usage possibilities for mining waste as construction materials, backfill material for supporting underground mines, underground constructions...
and surface mining workings and overburden spoils. [30], [31], [32], [33]

Mining related waste is mainly solid waste from separation and processing, operating solid waste from overburden removal and drifting, liquid waste from dewatering, processing and washing processes. Mining losses include mining waste water, mining influenced water, surface water, soil water, groundwater and mining water, mining influenced land and ground layers. [8] Other types are air pollution and land condition. Origin of mining waste is as following: Separation waste form HMS (heavy media separation), processing waste, crushing and screening waste. Mining related waste is mainly solid waste from separation and processing, operating solid waste from overburden removal and drifting, liquid waste from dewatering, processing and washing processes. Mining losses include mining waste water, mining influenced water, surface water, soil water, groundwater and mining water, mining influenced land and ground layers. [18], [19], [20] Other types are air pollution and land condition. Secondary waste from usage of mineral resources like burning, heating and constructing. The main properties of mining waste are chemical composition, compressive strength, cementation, solubility, resistance to freezing and calorific value. Waste properties are influenced by dilution, losses, selective extraction and specific mining processes. The information of the related studies is presented at the related website[3]. ETF Grants - Sustainable mining conditions, Backfilling of mines, Min-Novation - Mining and Mineral Processing Waste Management Innovation Network ,EuExNet, Mining water usage as heat carrier and several previous studies are bases for current study. [4] The main usage of solid mining waste is filling material, construction material, cementation material. Liquid waste can be used as heat carrier or as source for kinetic energy of water or for industrial usage. Waste as used land is used mainly as space for depositing, construction and recreation. Objects of the study are solid waste producing and usage, liquid waste producing and waste usage and land usage. The main mining waste related problem is optimising mining extraction, dilution, losses and waste producing balance. Second problem is finding optimal balance between processes of producing construction material or other products from mining waste and influencing extraction and processing in relation to waste usage. Third problem is finding optimal economical technology for producing mining waste originated products.

The experiments include e.g. chronometry of technological productivity, geometric and geological measurements, and measurements of rock quality. [15] The principal direction of developing mining technology is filling the mined area. This provides control over majority of environmental effects. Filling the workings decreases the loss of resources and land subsidence, and at the same time provides usage for stockpiling. Filling the spoils of surface mine decreases dewatering; harmless waste can be used for filling surface mines and in this manner offer new building land. Local land subsidence related to mining may extend also to technological networks. [34], [35], [36] The methods are: mapping the modelling criteria, indicators and processes of the mined areas; experimenting the possibilities of application, compatibility and results of mining software; applying laboratory experiments and fieldwork in modelling; creating models for blanket deposits (methodology in modelling MGIS, i.e. mining geoinformation system, models of new mines, changes in ground conditions, environment (modelling and analysis of groundwater dynamics, effects of dust, noise, etc.), geotechnological models in mined areas); applying seismological methods for developing theory for collapse risk, analysis methods for creating spatial models from geodetic spatial information, studies on material properties for developing theory for criteria for rock breakage. [9], [14]

In recent years, there has been a world-wide initiative for research, creating the concept of sustainable mining, using relevant indicators and making decisions based on them. MMSD (Mining, Minerals and Sustainable Development), SDIMI (Sustainable Development Indicators for the Minerals Industry), SOMP (Society of Mining Professors) and other international networks emphasize the need for creation of a concept for regional sustainable mining, relevant for local conditions. Three decades ago oil-shale mines of the former USSR including Estonia did not use the progressive mining methods with continuous miner, which are potential for the case of high-strength limestone layers in oil shale bed. Therefore, oil shale mining with blasting has been used as a basic mining method in Estonian miningfields up to now while continuous miner was tested for roadway driving only. As for cutting, the installed power of coal shearsers and continuous miners has increased enormously since the original work. The actual state of the market has changed, and a wide range of powerful mining equipment from well-known manufacturers like DOSCO, EIMCO, EICKHOFF, etc. is available now. Estonia has 30 years of experience in cutting with longwall shearsers which were not capable of cutting hardest limestone layer inside of the seam. Wirtgen surface miners have been tested (SM2100 and SM2600) as well as SM2200 and Man Tackraf surface miner, and still the testing of Wirtgen surface miner SM2500 for high selective mining in an open cast mine is being performed. The main field to be developed in addition to mine backfilling is mechanical extraction of oil shale. Potentially this allows increasing oil yield, decreasing CO2 pollution, decreasing ash amount, decreasing oil shale losses, avoiding vibration caused by blasting, avoiding ground surface subsidence (in the case of longwall mining), increasing drifting and extracting productivity compared with current room and pillar mining, increasing safety of mining operations. The final aim of the research is to use BAT (best available technology) for underground mining in areas with arduous conditions of coal and oil-shale deposits. The main problems to be solved are: selective cutting of oil shale (15 MPa) and hard limestone (up to 100 MPa), roof support at the face, stability of the main roof, roof bolting, pillar parameters, backfilling with rock or residues (ash) from oil production, water stopping and pumping in problematic environment (30 cum/t expected). Currently room and pillar mining with drift and blast technology is used underground. Supporting is done with bolts. Mining production is in total around 14 Mt/y, including
7 Mt/y underground. Total raw material amount underground is 12 Mt/y. Continuous miners keep playing a major role in the underground industry in over fourteen countries worldwide. A longitudinal cutting head-type miner was first introduced in the former Soviet Union by modifying the Hungarian F2 roadheaders and in the 1970s in Estonia by modifying the Russian coal roadheader 4PP-3. Evaluation of breakability was performed by a method developed by A. A. Sketchinsky Institute of Mining Engineering. For this purpose over a hundred samples produced by cutting of oil shale and limestone, as well as taken in mines by mechanical cutting of oil shale were analysed. Comparative evaluations were made by the experimental cutting of oil shale in both directions – along and across the bedding, including also mining-scale experiments with cutting heads rotating round (transverse heads) and vertical axes (longitudinal heads). In both cases the efficiency was estimated by power requirement for cutting. The feasibility was shown by breaking oil shale in direction of cutting across the bedding by using cutting drums on horizontal axis of rotation. The research also evidenced that the existing coal shearsers proved low endurance for mining oil shale. Better pick penetration of the longitudinal machines allows excavation of harder strata at higher rates with lower pick consumption for an equivalent-sized transverse machine. It was reported that with the longitudinal cutting heads the dust forming per unit of time decreases due to smaller peripheral speed. The change in the magnitude of the resultant boom force reaction during a transition from arcing to lifting is relatively high for the transverse heads, depending on cutting head design. Specific energy for cutting across the bedding with longitudinal heads is 1.3–1.35 times lower which practically corresponds to the change of the factor of stratification. These are the questions waiting for answers in the near future for effective oil shale extraction in Estonia and in similar mining conditions.

Countries which are involved in the Mining waste research with Min-Novation network (www.ttu.ee/min-novation) are mining countries with large amount of mineral extraction - coal, lignite, metal, oil shale and others. They have both historical and active mining waste facilities which continue to affect the environment. Using mineral raw materials from waste facilities will solve two important environmental problems: environment deterioration (soil, water, landscape) and saving natural mineral deposits. Because it strives to provide a substantial boost to the innovation and economic potential of mining waste management, it will on the one hand directly affect the existing waste management sector, and in an indirect way affect the mining sector. The entire life cycle of the mine will be taken into account, i.e. from initial excavation through operation to post-closure waste management. Thus, the sum total of waste landfilled will go down (by extension the sum total of waste re-used in a safe and environmentally neutral manner will increase), toxic waste will be more effectively neutralized, methods will be developed which will lead to improved recovery and removal of heavy metals from leachate. Such activities are part of a widely understood policy of protecting non-renewable resources.

The aim of the study is to find optimal balance of mining waste production, usage and influence to the minerals industry. It includes balance of mass, economy and properties of the source material, intermediate products and waste. Effect of optimizing is considerable. The main saving that can be done is within first stages in mineral extraction and usage. Proved “best available technology” allows starting utilising areas where mineral resource is found and can be easily mined. Support, selective extraction and backfilling allow optimising yield and loss balance so that benefit increases substantially. Underground dry separation, selective or course mechanical crushing, and cycloning are key technologies that can be applied for increasing mineral production yield.

II. METHODS

There are number of sustainable mining indicators and methodologies being used. Most of them are still in the developing stage. [6] The main tool for guiding those indicators is still taxation, penalties and relations to business reputations. [7] There are some organisations or individuals who have other motivators. There have been few tests being carried out for developing technological level. The primary motivator for this has been serious economic or legal problem.

The methods for analysing sustainability could be divided to the analyses of geometry, quality, quantity, technological primary processes and the mineral yield, limitations by the auxiliary processes and other economical and nature limitations. [40], [41], [42]

The main methods of analyses are spatial analyses, and balance methods of organic matter – freezing and thawing, sieving and breaking of the materials to be tested. For every mining process geometrical, properties and financial analyse will be done and transformed into complex chain of mining sequence. Data of the influences of mining exploration, rock breakage, rock processing is collected, produced and used. Additional activities of the study are collecting mining waste samples, analysing mining waste samples and data, analysing extraction and waste usage balance and testing waste processing techniques.

Geometrical conditions influence directly yield, losses, stripping ratio and rock mechanics. The deposits where mining has been performed in Estonia could be classified as shallow bedding deposits. [43], [44], [45] The largest area is limestone area, then peat and oil shale. Phosphorite is bedding deeper and by thicker seam as well as dictyonema shale. Granite is different as depositing as intrusion forming an ore body for mining.

The geometrical properties of the deposits influence in place tonnage, stripping ratio and therefore extraction cost. For opening limestone deposit the area of the claim is one of the factors. According the Estonian legislation 25 ha claim requires environmental impact assessment (EIA). It is presumed that influence to environment is critically large. The height of the high risk benches is 5 and more meters. In addition oil shale mining, blasting and underground mining automatically require EIA.
A. Processes
The primary processes are breaking, extracting, loading, haulage, separating and storage. Auxiliary processes are water removal and ventilation.

B. Selective Mineral Extraction
The series of tests with high selective surface miner have been performed in Estonian dolostone and limestone and oil shale surface mines with SM2100, SM2200, Man-Tackraf, Vermeer T2450, SM2200 and SM2500 in oil shale open cast mines. Rotating and cutting tools have been used and product and consumables measured.

The same principle has been used with longwall oil shale mining with cutting tools with oil shale seam shearers. Bank extracting influences directly geometrical parameters. Full seam extraction, selective and high selective extracting has been tested and implemented. Limestone full seam and selective layer extraction has been performed as well. Selectivity has been influenced by quality requirements of the product, water level, and in most cases administrative performance.

Layered extracting has been tested with surface miners, breaking with hands, chisels, with hydraulic and pneumatic hammer, with ripper excavator and with vibrio ripper excavator. Bulldozer ripper as well as breaking with excavator (both hydraulic backhoe and mechanical face shovel) bucket teeth has been used.

For dimensional stone breaking, levers, chisels, saw and bar cutter has been used.

C. Stripping
The stripping in the limestone and dolostone quarries has been performed mainly by bulldozer, backhoe hydraulic excavator or face shovel.

For oil shale surface mining, hand shovelling, steam shovel, dragline, and stripping shovel have been used. In smaller oil shale surface mines face shovel was planned for stripping as it was used for stripping limestone interlayers for selective mining of oil shale seam. Wider availability of hydraulic excavators has allowed using more flexible methods. Important stripping machine has been bulldozer in oil shale surface mines.

D. Blasting
In underground mining, longer face advancing has been implemented following short advancing, long wall mining with shearsers, with hand loading and room and pillar mining – both with partial backfilling. This is one of the possibilities for sustainable mining – underground space, mineral resource and ground stability was approached sustainably with selective mining, backfilling and minimal losses. The cost was high labour consumption.

E. Backfilling
Tests with fly ash, oil shale waste rock and sand mixtures were performed in several different conditions.

F. Separation
As well, dry separation of oil shale waste with Bradford type of drum screen and rotary impact hammer crusher was tested. AS well dry separation with crushing and screening buckets attached to wheel loaders and hydraulic excavators were tested for separating oil shale residues.

G. Mineral Quality
The mineral quality criteria are yield, losses, waste. With help of quality distribution it is possible to account for large volume of the mineral. Different locations and different layers were investigated in the case of cement limestone mining. Thanks to the wide distribution previously abandoned resource has been recalculated and approved as a construction limestone. Therefore the usage extent of the limestone deposit has been widened. The fines (0...4mm) are used as an additive to the cement production. P2O5 prolongers the hardening time of the concrete. In addition 30% in situ yield increase. It causes less influence to the land.

H. Separation
Dry separation was tested with Bradford drum previously. Recently disc-cutters as the bucket screening and crushing tests were performed with oil shale waste rock screened out form the oil shale run of mine with – 25 mm screens. (Fig. 1.)

Fig. 1. Dry screening and crushing of oil shale waste rock, cycle of the test.

I. Material Flow
Limestone fines are considered as waste rock, forming as a by-product of aggregate crushing. The study was conducted in larger limestone mining sites for analysing grain size of the fines. The samples were collected from representative places in fines spoils. Road construction standard was used as a base for sieving analyses. Class 0 to 0,063mm (1,4 to 2,4%) was
sieved and separated from the material. As well other classes were dried, sieved and weighted. Class 0.063mm to 2mm (48.5 to 68.6%) could be considered as limestone sand and 2 to 4 mm (24.2 to 31.8%) as a fine grain size aggregate for construction or for filling purposes.

And if screen out material sizes 0 to 0.063 that contains dust and clay, it is possible to use rest of it in a different ways. Like sizes 2-4 for sand, 4-8 for buildings. Size 0 to 0.063 is a small part of material only 1.49%. (Fig. 3. to Fig. 1.)

Fig. 2. Clayey particles less than 0.063 mm form less than 1.6% of the fines.

Fig. 3. Sieve analyses of the limestone fines.

Fig. 4. The grain size of Limestone fines.

I. Criteria

Vibration, noise, roads, nature protection areas, water, housing and as economic criteria: competition, shale oil, power generation are the main influences of the sustainable mining conditions.

K. Post Technological Processes

There exists a number of methods for undermined land evaluation. The first condition for choosing an evaluation method is the information about time, location and method of mining. When the condition is fulfilled, one has to choose a suitable evaluation method for a concrete study area. Such information can be obtained from old mining plans. To describe the situation in undermined areas, maps of old mining operations have been digitised (with scale 1:10000 and 1:5000), also showing the used mining method. For calculating potential amount of water the underground space and its properties should be defined. Since underground space forms from mine workings, roof structure and related water channels or tubes, this situation was mapped in 3D. Hydrogeological parameters have to be created and evaluated for defining underground space properties and classification of used mining technologies. Classification helps defining space that is available for water in abandoned mines [49].

Main tools for analysing amount of water in abandoned oil shale mines is computational modelling with spreadsheet models and designing the water flow with ModFlow water modelling software [51]. For the computational modelling we need to know how oil shale bed has mined (mining technology), how much space is in the old mine drifts and how water is moving between the mines. The model enables to assess the water levels in different mines and their border areas and to make assumptions and predictions about the water movement directions [49]. Using minewater in heat pumps, the best possible technical solution is: pumping the water through drillhole onto the ground surface. After lowering the temperature of minewater in heat pump about 1...4 degrees, the water is directed back to the mine or to the water source.

Fig. 5. North-South cross section of underground mining area and heat pump installation example.
### III. Results

Following result can be concluded:

1. The Best available technology is most profitable, easiest and friendliest technology that meets taxation requirements. Real development of the BAT or meeting best available sustainable mining conditions could be achieved with help of systematic and co-operative development program rather than through competitive and minimalist studies.

2. Minewater can be used for heating. Local heat pumps can be used in smaller places. Related to the stability, underground mining technology should be evaluated before building on the undermined surface.

3. Most of the limestone fines can be used as limestone sand for drainage layers.

4. Selective and flexible mining with quality distribution increases resource and decreases overall land disturbance.

5. Limestone aggregate quality management can be improved by determination the calorific value of the product. It gives the range of freezing and thawing.

6. Surface miner gives increase the output of oil shale up to 1 tonne per square meter. It means, that oil-shale losses in the case of SM technology can be decreased from conventional 12 up to 5 % that decrease the environmental impact. With controlling optimum cutting regimes and parameters it is possible stabilizing fuel consumption inside the optimum area. Energy consumption during the rock cutting can bedecreasing up to 45% not only by the means of right cutting tools usage but by the way of thickness to speed ratio (h/V) regulation also. [1] The productivity can be increased with modernising stripping scheme and prolongation the surface mining sections.

7. The optimum condition in abandoned production peat fields is permanently high (0.2–0.5 m below the ground surface) groundwater. In most part of the abandoned milled peat fields the groundwater lies deeper (up to 1.1 m), which creates unfavourable conditions for the re-vegetation. [50]

8. Oil shale mining is possible under wetland, when applying following conditions: dimensioning up the pillar size, avoiding drilling drill holes or shafts through impermeable layers. Underground longwall mining would be more economical and less disturbing to the environment than surface mining. The yield would be maximal in both cases.


10. The main obstacle for developing sustainable mining practice is the attitude and cooperation of the ministries, culture of the company and engineering and analytical level of their managements and cooperation with related institutions. There are no major economic or technological problems to apply sustainable mining practice in all required stages.

11. The main developments needed to apply sustainable mining practice in Estonia is toanalyse backfilling mining possibilities and perform pilot tests, analyse longwall and shortwall mining possibilities and analyse separation technologies for oil shale, phosphorite and dictyonema shale. In addition the main bodies of authorities such as mineral commission should start working on consensus and modern administrative level.

### IV. Discussion

Complex usage of mineral resources creates sustainable management practice (smp). One of the options would be having very clear and understandable criteria for both sides – miner and land owner. For example the extent of allowed depression cone instead of multiword discussions around this topic that is wasting time and money.

One of the problems is definition or range of evaluation criteria. It should take into account all influences, best available science results and always be argued with conclusion that is consensus. Often this is not the case and is hidden behind bureaucracy, politics and business interests.

In opposition to currently wide spread customs and principles, mining is possible in any circumstances, provided that sustainable mining environment has been created. In other words, with the proper choice of mining technology, the effect of mining has been damped below the level that the nature and man can tolerate. It is possible to manage and optimise the processes and performance of the mining influence and cost sources (water inflow, waste generation, selectivity range of the extraction, technology oriented to cleavage and faults system) so that the negative influence would decrease and remarkably in relation to current practice.

### Table I

**Optimum Capacity on 10MW as Large Scale Pilot Plant**

<table>
<thead>
<tr>
<th>AT</th>
<th>Heat production, kW</th>
<th>Water needed, m³</th>
<th>Pumps needed</th>
<th>Electricity for pumps, kW</th>
<th>Heat pumps needed</th>
<th>Electricity for heat pumps, kW</th>
<th>Summary of electricity, kW</th>
<th>COP</th>
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<td>8592</td>
<td>8</td>
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The methodology and criteria for planning, designing, modelling and accepting of sustainable mining environment will provide the base for mineral raw material that the economy requires, both in near and far future. The conditions for optimal mining can be applied for all Estonian resources, including so far not utilized sites of granite, graptolite argillite (raw material for uranium) and phosphorite. They can also be applied in analogical mining conditions (blanket deposits) outside Estonia, particularly in the case of oil shale (Russia, Ukraine) but also for coal, brown coal, salts, etc.

The actual (measurable) effect of mining is up to a magnitude level smaller than is claimed. Because of this fact, the real (based on measurements) environmental restrictions should be less strict in the respective amount.

In hydrogeological circumstances of plentiful water, such as the Toolse-Lääne study are of the mining region of Rakvere-Kunda, it is possible to find a usage for the water that is pumped out.

The principal direction of developing mining technology is filling the mined area. This provides a control on majority of environmental effects. For instance, filling the workings decreases the loss of resources, land subsidence and at the same time provides usage for stockpiling; filling the berm of an surface mine decreases the dewatering; harmless waste can be used for filling open mines and in this manner create new building land. Local land subsidence is related to mining, extending also to technological networks. It is possible to find out the deformation parameters by geodetic monitoring. Taking these parameters into account make it possible to model further the extent and effect of the deformation.

The basic mining research will be performed with modern geostatistical and technological modelling methods. Detailed spatial model of rock, water, technology and mining processes will be built related to mining conditions. The main processes and performance that is being analysed is as following: geostatistical distribution of mineral quality, the capital constructions and investments in relation the geotechnical conditions, dependence of rock breakage and extraction mechanics from mining conditions. [16] Material handling, haulage, storage, reclaiming, supporting, drifting, processing, separation, enriching, distributing and cost and influence of the supplementary processes like water removal.

Principal methods are related to introducing sensors, measuring equipment and mining condition experiment, matching structures of various data and modelling based on them. The methods are:
1. Mapping the modelling criteria, indicators and processes of the mined areas
2. Experimenting the possibilities of application, compatibility and results of mining software
3. Applying the laboratory experiments and fieldwork in modelling
4. Creating models for blanket deposits (methodology in modelling, MGIS, i.e. mining geoinformation system, models of new mines, changes in ground conditions, environment (modelling and analysis of groundwater dynamics, effects of dust, noise, etc.), geotechnological models in mined areas)
5. Seismological methods for developing theory for collapse risk
6. Analysis methods for creating spatial models from geodetic spatial information

As a result, conditions for creating mining environment satisfying all involved parties (industry, state, public, decision makers) will be developed, being applicable for any deposit of any resource. A system of criteria of evaluating the mining environment will be designed.

Created methodology contains evaluating and influencing algorithms and principles of vibration, dust, noise, water usage, water lowering, water energy usage, technogenic fissures and weakening of support pillars with water solution and movement, tectonic faulting, water inflow, ventilation, processing, mineral enriching and ground stability related to mining activities and underground space creation. [26], [27], [28]

Basis will be created for compiling a development plan for mining the resources, zoning and criteria for compilation of the plans.

The first step will be geological and mining-related zoning of principal mining regions of Estonia. The choice is made among Lääne-Harju (Vasalemma, Padise, Harku etc. deposits), Ida-Harju (Lasnamäe, Vao, Maardu, etc. deposits), Kunda-Rakvere (Toolse, Ubbja, Auru etc. deposits) and Ida-Viru (Estonian oil shale deposit, Pahautu peat deposit and a few areas of mining building material. Criteria will be provide for applying optimal mining technology for surface and underground oil shale mines and problematic deposits of building material, supposedly Nabala, Kunda and Ida-Harju region. The goal is more effective usage of resources and minimal negative environmental effect, having in mine of planning new large buildings, main roads and underground structures.

The results provide better understanding between the public and the miners, and ahead a basis for well-argumented communication, and promotion for Estonian economy in the manner that satisfies both parties.

In recent years, there has been a world-wide initiative for research, creating the concept of sustainable mining, using relevant indicators and making decisions based on them. MMSD (Mining, Minerals, and Sustainable Development), SDIMI (Sustainable Development Indicators for the Minerals Industry) and other international networks emphasize the need for creation of a concept for regional sustainable mining, relevant for local conditions. At the same time, modelling systems are built and usage of non-traditional fuels is being started. The proposed research project gives an opportunity for being in the forefront of research on sustainable mining, both in Estonia and globally.

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Karu, V. Amount of water in abandoned oil shale mines depending on mining technology in Estonia. In: 9th International Symposium "Topical problems in the field of electrical and power engineering. Doctoral school of energy and geotechnology": Estonia, 2010. Tallinn: Tallinn University of Technology