

## Final Project Report

### 1. Contestant profile

▪ Contestant name:	Anna-Helena Purre, Kadi Padur
▪ Contestant occupation:	PhD students
▪ University / Organisation	Tallinn University
▪ Number of people in your team:	2

### 2. Project overview

Title:	Optimising post-mining land-use decision-making in cooperation with stakeholders. Involving stakeholders and optimizing the decision of quarry re-use using multi-criteria decision analysis – example of Estonian limestone, oil shale and clay quarries
Contest: (Research/Community)	Community
Quarry name:	Mereäärne, Aru-Lõuna, Toolse-Lääne and Ubja quarries in Estonia

## Abstract

There are several possibilities for rehabilitating quarries after mineral resource excavation. In Estonia, creating forest, water body, meadows, arable land or recreational area are mainly used. To choose the optimal alternative for each site, several legislative, environmental, and socio-economic criteria should be considered in a systematic way. To increase the transparency of such decision and create a basis and tool for choosing optimal re-use alternative for quarries, we created a decision model that contains decision-tree with restrictive criteria and decision matrix with comparison criteria, and chose re-use alternatives for four quarries operated by Kunda Nordic Tsement.

Decision-tree was created in cooperation with experts from mining companies, Environmental Board, and environmental consultancy companies, and based on environmental and legislative criteria. To find out the comparison criteria weights 93 representatives of stakeholders such as land owner, representatives of local community, experts from governmental agencies in the field, environmental NGOs, universities, environmental management companies and mineral resource excavation companies were engaged to stakeholder survey.

Using developed decision model, we found that for Aru-Lõuna and Toolse-Lääne limestone quarries and Mereäärne clay quarry the only implementable re-use alternative is to create a water body. In Ubja oil shale quarry several re-use alternatives were possible (meadow, afforestation, recreational land, and arable land) to apply according to decision tree and the decision matrix showed that afforestation was the optimal re-use alternative for that site. The model supported previously done decisions on all analysed quarries. The decision process described in this project supports the sustainable land-use and aids in sustaining and creating higher biodiversity inside the quarries, by incorporating criteria such as estimates of biodiversity and compliance with green network of re-use alternatives to the model. Our improved decision process also supports the biodiversity outside the quarries, as in cooperation with experts and other stakeholders important step was added to the decision-making process, which should support the excavation all differently categorised mineral resources from the current quarries and with these decisions in the same time reduces the need for preparing new quarries in unaffected areas. With some country-specific modification the model can be applied also in other countries to make these kind of decisions optimal and more transparent for stakeholders.

### 3. Introduction

About 2% of Estonian land has been disturbed by land-resource excavation (Ministry of Environment, 2018<sup>1</sup>), from which sedimentary minerals such as oil shale, peat, and mineral resources used for construction (sand, gravel, limestone, clay, dolomite) are excavated. In 2015, about 10 million tonnes of oil shale was excavated in Estonia, while about 5 million cubic meters of sand and gravel, 2.5 million m<sup>3</sup> of limestone and dolomite, and 32 000 m<sup>3</sup> of clay was excavated (Land Board, 2016). Excavation from quarries is prevailing in Estonia, while large quantities of oil shale is excavated also via underground mining. According to Earth's Crust Act (§ 48), quarries where mineral resource excavation has finished should be rehabilitated by mining operator to ensure sustainable land-use and mitigated dangers and negative impacts of quarries. Estonian Ministry of Environment organises the rehabilitation of state-owned unrehabilitated quarries from Soviet era

Rehabilitation decision should be achieved with social acceptance within the region, assist the natural balance of the local ecosystems and be in visual accordance with the surrounding landscape. The alternatives are generally urban related, rural production, recreation or conservation. The main quarry rehabilitation options applied in Estonia are creation of water body (average depth at least 2 m), forest, meadow, arable land or recreational land. Creation of wetlands is not allowed in Estonia as shallow water bodies lead to paludification in shorter or longer times-scales, and creating conditions for paludification is prohibited according to Estonian Water Act (§ 33). Also leaving quarries for self-recovery is prohibited by Earth's Crust Act. In Estonia, quarries have been turned to areas for motosports, skiing, rowing, swimming and extreme sports in case of recreational use.

The decision between after-use of the quarry depend on many factors such as environmental conditions, location of the quarry and its surrounding areas, legislation, interests of owner of the quarry property, local municipalities and communities, and so on. The implementation of different land-use alternatives has various impacts, which have to be considered based on multiple criteria. In the environmental decision-making such as quarry rehabilitation decisions, compromise between interdisciplinary socio-political, environmental and economic effects are required considering different views of various stakeholders (Huang et al. 2011).

To make well-grounded decisions where conflicts and disagreements of stakeholders' opinions are eradicated with engagement in transparent, traceable and well-structured decision making process, decision-makers should use methods engaging variety of views, values and information. It has not yet been defined, which aspects should be considered in the selection of rehabilitation alternative for different quarries. The aim of this paper is to improve the decision making of rehabilitation of open-cast mining areas of mineral resources (sand, clay, gravel, limestone, oil shale) to ensure sustainable land-use. Our objectives are to:

- develop a decision model, that contains:
  - decision-tree with restrictive criteria developed in cooperation with experts,
  - decision matrix with rehabilitation alternatives and weighted comparison criteria developed in cooperation with stakeholders;
- select an optimal quarry rehabilitation alternative for four example quarries in Estonia belonging to Kunda Nordic Tsement.

We chose four quarries (Appendix 1: Table 1 and Figure 1) operated by Kunda Nordic Tsement (part of Heidelberg Cement AG) in Northern Estonia for the project. All quarries are located in Lääne-Viru County, Municipality of Viru-Nigula. Mereäärne clay quarry is situated 1 km from the residential buildings in the small town of Kunda, and about 400 m from the Baltic Sea. Aru-Lõuna, Toolse-Lääne and Ubja quarry sites are located about 4, 6 and 9 kilometres respectively from Kunda. According to Statistics Estonia (2018) over 1 200 citizens are living in rural areas of Viru-Nigula municipality, and over 3 000 in Kunda. Ubja quarry is in Ubja village with population of 300. So there is strong public interest for the rehabilitation options of these quarries.

Our team consists of PhD students of ecology in Tallinn University. Kadi Padur has a background in environmental management and she focuses on using multi-criteria decision-analysis to optimise environmental management decisions in her PhD studies, and lectures also this subject to the master students. Anna-Helena Purre has background in plant ecology on peatlands, and she analyses connections between vegetation and biogeochemical cycles on restored milled peatlands.

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<sup>1</sup> See Appendix 2 for list of references in this report and other appendixes.

## 4. Actions and activities

Multi-criteria decision analysis (MCDA) process contains steps like defining the problem, goal establishment that solves the problem, identification of the alternatives that should meet the goal, developing evaluation criteria, implementation of the comparison method to solve the decision matrix and find out the optimal alternative. MCDA use different inputs (scientific studies, expert opinions, modelling, cost/benefit analysis and preferences of stakeholders) to rank various alternatives. In the project we defined the stakeholder groups and developed a decision model by creating decision-tree in cooperation with the experts and decision matrix in cooperation with stakeholders. We compiled and conducted a survey for stakeholders, analysed the results and found weights for comparison criteria. Afterwards we found values for comparison criteria in case of each alternative, and built up the decision matrix. Finally we applied the developed model on four quarries operated by Kunda Nordic Tsement.

### 4.1. Cooperation with stakeholders

Stakeholders were firstly engaged through interviews to develop a decision tree. We interviewed private sector — personnel from AS Kunda Nordic Tsement (mining company) and companies compiling the Environmental Impact Assessments (EIA) for mining companies, and governmental sector (Environmental Board). We considered those stakeholders to have largest knowledgebase about the legislation and practicalities of deciding the re-use alternatives for quarries in Estonia.

Afterwards, we involved stakeholders and conducted a stakeholder survey via internet. According to classification by Grimble and Wellard's (1997), two major stakeholder categories are: (1) primary stakeholders, who are mostly affected by the outcome of the project in a positive or negative way, and (2) secondary stakeholders, who are not directly affected by the outcome of the project, but have an interest in it, e.g., government agencies, funding institutions, monitoring agencies, non-governmental organisations or private sector key individuals. In this project **primary stakeholders** are (1) landowners (in this project the sites are on public lands and they are managed by Land Board, while some other quarry areas are managed by State Forest Management Centre), (2) mining companies (in this case AS Kunda Nordic Tsement, whose responsibility is the rehabilitation of the area in the end of the extraction process; the other mining companies were also involved to the survey), (3) local people, who are represented by the local municipalities (there are at least some quarries on the territory of all the local municipalities in Estonia, so all local municipalities received an invitation to participate in the survey). The **secondary stakeholder** are (1) decision makers and governmental organisations (Environmental Board, Ministry of Environment, Ministry of Economic Affairs and Communications), (2) non-governmental environmental organisations (e.g. Baltic Environmental Forum, Estonian Society of Ornithologists, Estonian Council of Environmental NGOs), (3) environmental management companies (ten larger environmental management companies received the invitation to the survey) and (4) scientists (geologists, ecologists and environmental management scientists from the Estonian universities and research agencies).

A total of 400 people were asked to take part, and 93 of them participated in the survey. Questions asked from the stakeholders in the survey to obtain an overview of their opinions about the topic and for developing the weighted comparison criteria for quarry rehabilitation decision making are in Appendix 1 Table 2. Stakeholders were competent on quarry rehabilitation field and had practical experience and/or theoretical knowledge on the subject (Figure 1).

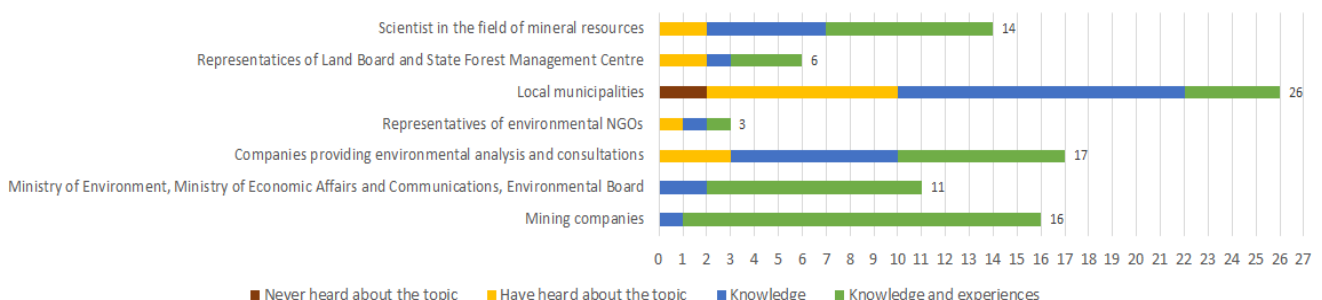


Figure 1. Overview of previous experience with the subject across all stakeholder groups

## 4.2. Development of the decision model: criteria, decision tree and decision matrix

Criteria in this project divide into restrictive and comparison criteria. Restrictive criteria are organised as a decision-tree allow to reduce the number of rehabilitation alternatives by discarding those alternatives that are not implementable in specific quarry (Sanchez-Lozano et al., 2013) due to environmental or legislative reasons. In this project restrictive criteria were developed in discussions with experts and based on the supportive literature and legislation. The importance of those restrictive criteria were supported by the stakeholders participating the survey (Appendix 1, Table 2.). The improved quarry rehabilitation decision making process contains decision-tree as a sub-process and is developed based on process modelling principles in Bizagi Modeler 2.9.0.4.

To compare and rank the rehabilitation alternatives we developed weighted comparison criteria, which do not prevent the implementation of the alternatives, but they will point out the significant differences, advantages and disadvantages of the available reuse options. The criteria were determined by experts and their weights (Figure 3, Table 1) with the stakeholder survey as proposed by Fontana et al. (2013). We calculated average values of each criterion within each stakeholder group and then averaged across all stakeholder groups. This ensures that all stakeholder groups are considered equally, and so being independent of the number of respondents in each stakeholder group. Comparison criteria values are taken from or calculated based on literature, planning documents or asked from relevant stakeholders. We developed decision matrix with comparison criteria and applied SAW (Simple Additive Weighting) method for ranking. This technique is one of the simplest, natural and most widely used multicriteria evaluation method, integrating the values and weights of criteria into a single estimating value. In the decision matrix, comparison criteria values must be normalised the range zero and one, where the most preferred value is 1 and less preferred is 0 (Podvezko, 2011). SAW method is based on weighted sum where the optimal alternative gets the highest value. Regardless of chosen SAW method in this project, it is possible to implement other methods to solve the decision matrix if the decision maker would like so.

## 5. Results and discussion

### 5.1 Improvements to the decision process, restrictive criteria and decision-tree

In the survey almost all respondents stated that if a probable economic or probable potentially economic reserve lies below the proved economic reserve that is going to be excavated, the potential value and usability of the bottom reserve need to be assessed. So, on addition to today's administrative proceedings of excavation permit (that contains EIA and other process stages) after the submission of excavation permit the first new step for decision makers should be verification if there are registered probable and/or potentially economic reserves under the proved economic reserve (Figure 2 process 1), which are defined by Earth's Crust Act (Appendix 1. Fig. 2). This categorisation is changeable if the circumstances serving as a basis for determining mineral reserves have changed.

Adding this step to decision tree supports the sustainable use of land and resources, and mitigates negative impacts to the environment. According to most respondents, optimal is to excavate all of the reserves in one place, regardless of a category of the reserve if it is possible. This reduces the need to open new mining sites in so far unaffected places as excavation has an environmental impact anyway. This is also coherent with the principles of the Estonian mineral resources policy. Secondly it is reasonable to impact one place for a longer time to excavate all the reserves as local people are used to the impacts of excavation there. Thirdly, if area is rehabilitated (for example as a water body) and years later the bottom reserve is re-classified as proved economic reserve the excavation of the reserve could be very difficult and rehabilitation of the same area twice is not rational use of resources. The fourth important argument is as the resource category (proved economic, probable economic, probable potentially economic) is set in certain time based on economic and environmental criteria of which may change over time, so it is reasonable to re-assess the resource category before planning the rehabilitation.

Until the national analysis of possibilities to re-categorise and re-register probable economic or probable potentially economic reserve to proved economic reserve is carried out the extraction permit for proved economic reserve is issued without determined rehabilitation option. If analysis shows that the reserve is suitable to re-categorisation as proved economic reserve it should be re-registered. So extraction will be continued with the bottom layer of re-categorised proved economic reserve and rehabilitation option is selected using MCDA for the area when all proved economic reserves are extracted. Otherwise, if analysis shows that the reserve is not suitable to re-categorisation as proved economic reserve, rehabilitation option for already issued permit will be determined using MCDA before planning the rehabilitation. Depending on the site-specific conditions MCDA model contains one or two sub-processes (Figure 2 sub-processes 1.1 and 1.2).

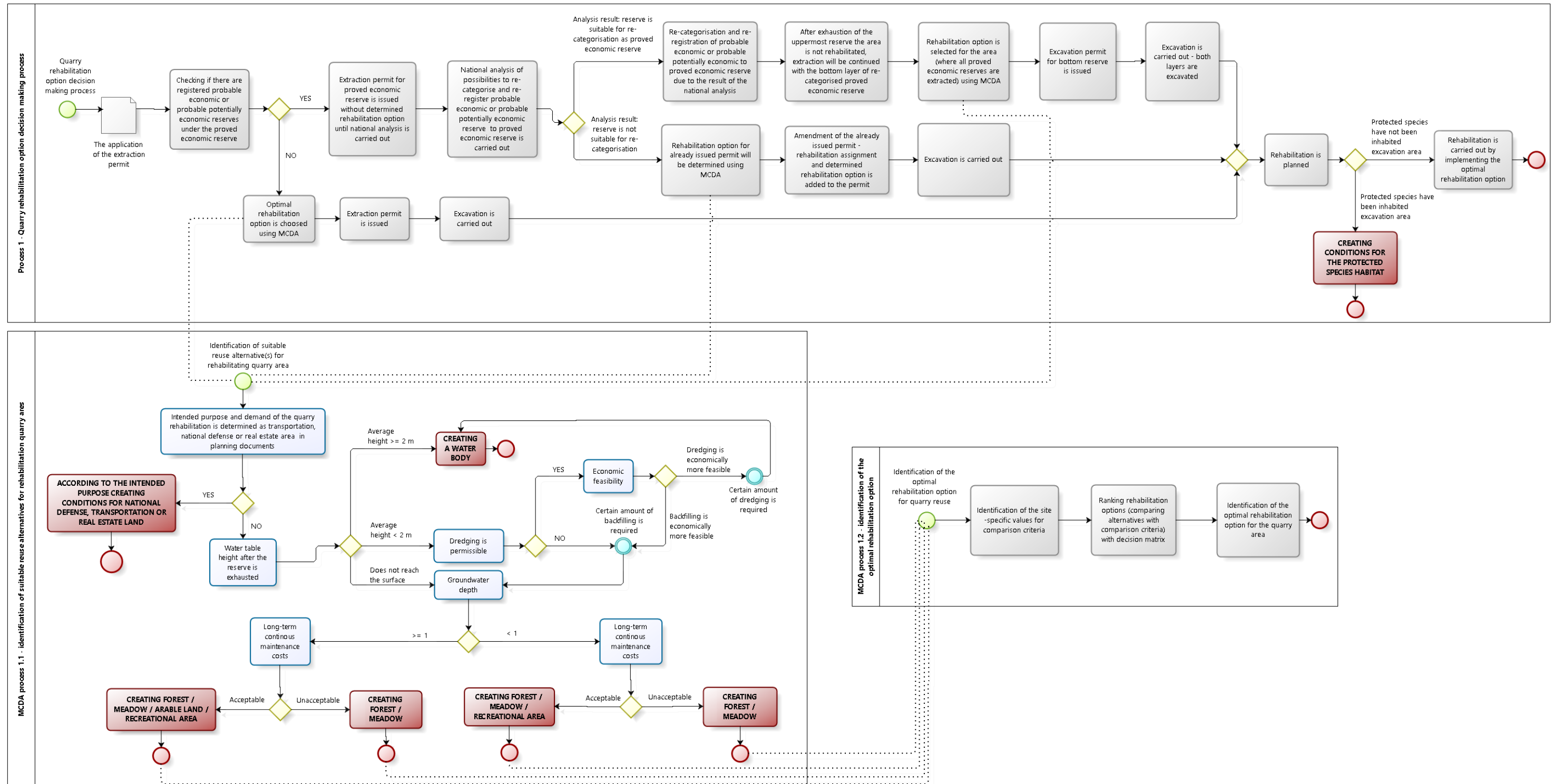
Developed decision tree (Figure 2, subprocess 1.1) contains following restrictive criteria and their values:

- **intended purpose** of the quarry rehabilitation is determined as transportation, national defence or real estate (urban) area in planning documents: in some cases the decision of the quarry area reuse is previously done based on needs (transportation and national defence land) or demand (development/urban area) in the planning documents, so this must be taken into account;
- **water table height after the reserve is exhausted:** Arbogast et al. (2000) emphasize that the height of water table and if the water table is below or above the quarry surface is one of the main criterion that influences possibilities of different quarry reclamation options (Table A1). If the water table height is averagely at least 2 m (Minister of Environment 07.04.2017 Regulation no 12), the optimal reuse alternative is to create a water body;
- **possibility and feasibility of dredging:** if water reach the surface, but the average height is less than 2 m, the possibilities and afterwards the economic feasibility of dredging and backfilling must be analysed;
- **groundwater depth:** if water does not reach the surface (in the end of excavation or after backfilling) the next restrictive criterion is the groundwater depth. If it is quite close to the surface (less than 1 m deep) the creation restricts the implementation of arable land as the reuse alternative (Minister of Environment 07.04.2017 Regulation no 12), because part of a year it could be too wet for harvesting;
- **acceptability of fixed maintenance cost after rehabilitation:** in Estonian it is rather common practice that rehabilitation of recreational or arable land is restricted because after rehabilitation subsequent maintenance cost is not acceptable for landowner (e.g. governmental organisation). These reuse alternatives need constant resources for maintenance in comparison with forest and meadow areas where, according to the experts in Environmental Board and State Forest Management Centre, maintenance costs are so low that it is acceptable to implement these alternatives in any case
- If **protected species** have habited the quarry area during excavations, the quarry or part of it must be rehabilitated for the habitat of the protected species (§48, Nature Conservation Act, 2004).

In case of Aru-Lõuna, Toolse-Lääne and Mereäärne quarries, there are no intended purpose (national defence or transportation land) defined for the quarry area and no interest for the urban development in these areas according to the stakeholder survey. In these three quarries average water table height is over 2 meters after excavation. Therefore there is a single possibility to re-use those sites as a water bodies according to the decision tree if there is no habitat of protected species by the end of excavation. In these cases it is not possible to use comparison criteria to rank different implementable alternatives, because only one alternative is suitable. Decision making ends as the optimal reuse alternative is identified. In Ubja quarry, there is also no intended purpose set for the land. Unlike other sites, the groundwater does not reach the surface in Ubja and stays below one metre depth in average. We consider continuous maintenance costs acceptable in that case to allow all possible rehabilitation options (forest, recreational land, meadow, and arable land) to the comparison part of the decision model. Developed weighted comparison criteria and the decision matrix is described and applied in the next section.

Underneath economic proved reserves in Aru-Lõuna, Toolse-Lääne, and Ubja are also probable economic reserves of phosphorite, and in Mereäärne quarry is proved potentially economic reserve of cement clay (Appendix 1 Table 1). So before choosing the optimal rehabilitation option, national analysis of possibility, potentiality, environmental feasibility, and usability of the reserves of phosphorite and cement clay should be done before the rehabilitation plan is prepared. If the analysis results show the re-categorisation of those reserves are possible the excavation of all reserves should be done to support sustainable land-use. The optimal rehabilitation alternative should be identified for the area considering site-specific conditions that describe the situation after all reserves are exhausted.





**Figure 2.** In the figure part “process 1” are the improved decision making process steps, in the part “MCDA process 1.1” is developed decision-tree with restrictive criteria, their values and implementable rehabilitation alternative(s) in certain conditions – if there is only one suitable option, it is the optimal reuse alternative for the site, but if there are more than one implementable alternative, then MCDA process contains also the part “MCDA process 1.2” where are the process steps for identification the optimal reuse alternative for the quarry.

## 5.2 Weighted comparison criteria and decision matrix

Developed weighted comparison criteria and their values for each re-use option were derived from literature, planning documents and databases and their weights were identified as the result of the stakeholder survey:

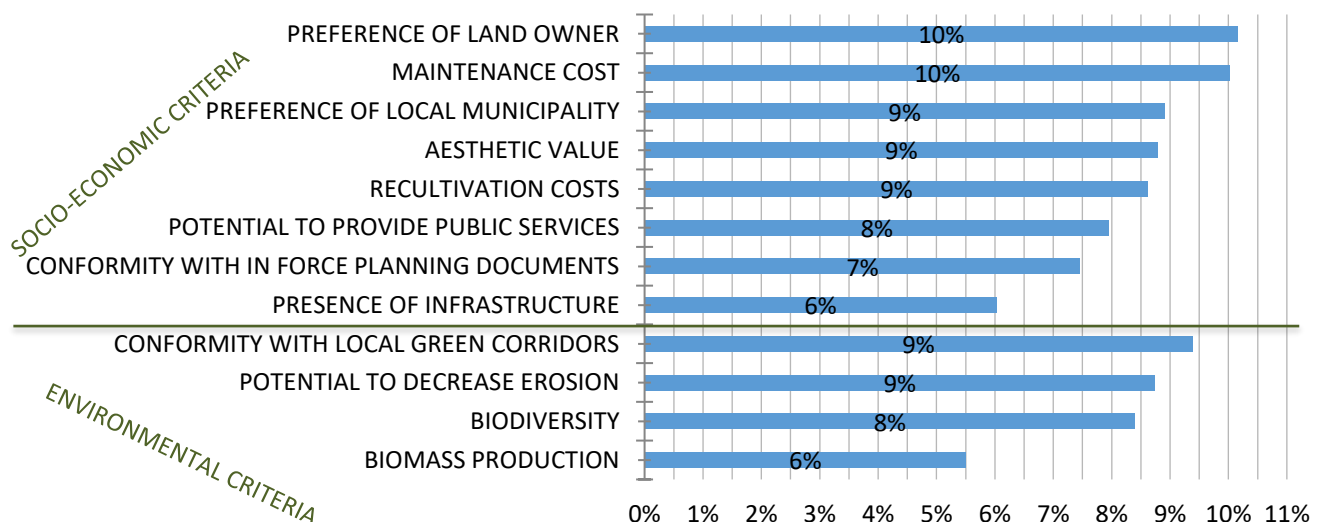
- **Recultivation cost.** Quarry recultivation divides into technical and biological recultivation. Technical cultivation includes creation of suitable, safe and strong quarry slopes and return of soil cover where needed. As overall requirements of technical cultivation are similar in case of all recultivation options (Sein & Reinsalu, 2017), it is not calculated in the cost of recultivation costs, if special works are not needed for application of some recultivation option. Costs of biological cultivation is described in Appendix 1 Table 3. In the decision matrix we normalised the values, so higher values indicate the less expensive values.
- **Maintenance cost.** According to Estonian Earth Crust Act (2017), excavation company must ensure that the applied reclamation option is standing for at least three years after approval of quarry reclamation. Maintenance costs of each alternative are brought out in Appendix 1 Table 3. In the decision matrix we normalised the values, so higher values indicate the less expensive values.
- **Presence of infrastructure.** Technical infrastructure such as power supply and access roads are emphasized by Kalberg and Niitlaan (2017) in case of real-estate and industrial development, but also in case of some recreational recultivation (e.g. mountain skiing infrastructure needs large power supply). So the criterion gives an advantage for recreational area (one point on the scale 0 to 1), while in other re-use alternatives this criteria does not play any role (zero points) – it does neither prevent nor support others.
- **Aesthetic value** is the most emphasized cultural ecosystem service of landscape (Plieninger et al., 2013). In Northern Europe, mainly seminatural landscapes such as treed meadows are preferred (Klein, 1972). In agricultural landscapes local people value highly hedgerows and treelines, but also presence of livestock and forest patches is important (van Zanten et al., 2016). Presence of water bodies increases aesthetic value of the site, with stronger positive effects on woody and forest vegetation, while presence of arable land has very strong positive impact on aesthetic value of the site when it is not dominant (Svobodova et al., 2015). Low and negative aesthetic values are attributed to landscapes with active mining sites and mining infrastructures and machinery, but also to urban and rural structures (Ramos & Panagopoulos, 2006; Svobodova et al., 2015). So meadows and recreational land obtains maximum score, forest obtains 0.5 point and arable land zero points in the scale 0 to 1.
- **Preference of local municipality and land owner** are site specific comparison criteria that should be asked in case of recultivation of every quarry. According to Earth's Crust Act § 81. (5) Environmental Board has to ask opinions of local government and land owner about the conditions for quarry reclamation, and also if the quarry is in the land of a construction work that serves national defence purposes or its protection zone, also the opinion of the Ministry of Defence must be asked. Local municipality as a representative of local community has important part in developing conception of quarry reclamation and landowner has to maintain the applied rehabilitation option (Kalberg & Niitlaan, 2017). We asked the preference of local municipality of all the quarries, and Land Board (representative of state as a land owner) in the extended stakeholder questionnaire. Results for Ubja site, where several reuse options were possible, are in the Appendix 1 Table 4.
- **Potential to provide public services:** According to Kalberg and Niitlaan (2017) public interest is greatest in case of recreational area, also in case of water body if the quarries are situated near the settled areas and are easily accessible, while forests provide less public services. Plieninger et al. (2013) report that highest potential to provide public services have water bodies (aesthetic, walking, swimming), and forests and meadows (gathering wild products, walking, education), while arable land has low potential to provide public services. More preferable reuse option should have the higher score in the scale 0 to 1.
- **Conformity with the planning documents:** This criterion supports reuse alternatives that conforms to documents, but as documents are changeable it is not restrictive criterion. According to the planning documents of Sõmeru municipality (E-Konsult, 2006) Ubja quarry area is defined as forested land, so this reuse option got maximum score (1 point), while other reuse alternatives did not get points in scale 0 to 1.
- **Biodiversity:** HeidelbergCement AG (2010) have evaluated the biodiversity of meadow to be the highest, especially in case of herbaceous plants and insects, while biodiversity of arable land is low (monoculture). In commercial forest biodiversity is low, while natural forest provides large number of ecological niches that support biodiversity, while biodiversity is also low in development and recreational land, but depends on anthropogenic use (HeidelbergCement AG, 2010) (Appendix 1 Table 5).
- **Conformity with green corridors:** Recultivation should support the green corridors and core areas if quarries are located in these areas (Kalberg & Niitlaan, 2017). Ubja is surrounded by green corridors (E-Konsult, 2006), and forested parts of the Ubja functions as green corridors. To support the green corridors, it is advised to rehabilitate the quarry sites to forest (E-Konsult, 2006; Kalberg & Niitlaan, 2017), so the higher score (1 point) is given to that reuse option in comparison with other quarry rehabilitation options



in the MCDA decision matrix and lower scores for others (on the scale of 0 to 1), but if quarry area is not situated in the green corridors, the criterion is not supporting any reuse alternatives and is not used.

- **Potential to decrease erosion:** Quarry reclamation should mitigate dangers to humans, animals and vegetation including erosion. To quantify the erosion reduction, we use cover-management (C) factor, which accounts for how land cover, crops and management cause erosion to vary from that occurring in unvegetated areas (reference conditions, factor value 1), so lower C-factor counts for higher soil erosion reduction (Panagos et al., 2015). In the decision matrix we normalised the values from Appendix 1 Table 6, so higher values indicate higher erosion reduction.
- **Biomass production** provides possibilities for economic use of biomass, but biomass also supports functioning of ecosystems and biogeochemical cycles. Biomass production in different reuse possibilities (Appendix 1 Table 7) were averaged within each reuse category and normalised in the decision matrix.

Comparison criteria weights developed in cooperation with stakeholders. The preferences of different stakeholder groups were rather similar as it is shown in the Figure 3 in Appendix 1. But for example the opinions of the members of NGO's are inclined to environmental aspects like biodiversity and area's conformity with the local green corridors after rehabilitation contrary to almost everyone else's opinions that are inclined to landowner's preference as one of the most important criteria. Considering all the opinions comparison criteria weights were found (Figure 3). The most important criteria are the preference of landowner (10%) and maintenance cost (10%). Four of twelve criteria are environmental and eight are socio-economic aspects. The results show that the sum of the environmental criteria is 32% and the sum on the socio-economic criteria is 68%, therefore it is possible to state that environmental, social and economic aspects are equally important parts in the quarry rehabilitation decision making.



**Figure 3.** Comparison criteria weights that are developed in cooperation with stakeholders.

In the decision matrix all values for each reuse alternative among each comparison criteria were normalised in the scale 0 to 1 so the 1 is the highest (best) value for criterion. In the decision matrix we used SAW method to rank the reuse alternatives using criteria weights and normalised values. In Ubja quarry, forest was the optimal reuse alternative, followed by recreational area, meadow and arable land. The complete decision matrix with normalisation and calculation steps is in Appendix 3.

**Table 1.** Multi-criteria decision-making model decision matrix for choosing optimal reuse alternative for quarries. Grey shaded areas show site-specific criteria values for Ubja quarry, green shaded indicates calculated weighted sum and according ranking of alternatives for Ubja quarry.

Criteria weights (%)	Criteria	Quarry reuse alternativesRe				Source of criteria values
		Forest	Meadow	Arable land	Recreational land	
9	Cultivation cost (€/ha)	0	0.63	0.4	0.71	Table A.3
10	Maintenance cost (€/ha year)	0.67	0.68	0	0.75	Table A.3
6	Technical infrastructure	0	0	0	1	4.3.3. weighted comparison criteria
9	Aesthetic value	0.5	1	0	1	4.3.3. weighted comparison criteria
10	Preference of landowner	0.75	0	0.5	0.25	Questionnaire, Table A.4
9	Preference of local people	0.75	0.5	0	0.25	Questionnaire, Table A.4
8	Potential to provide public services	0.5	0.5	0	1	4.3.3. weighted comparison criteria
7	Planning documents	1	0	0	0	Planning documents concerning the area
8	Biodiversity	1	1	0	0.5	Table A.5
9	Green corridors	1	0	0	0	Planning documents concerning the area
9	Potential to reduce erosion (C-factor)	1	0.72	0	0.79	Table A.6
6	Biomass production t/ha	1	0.46	0.77	0.46	Table A.7
	<b>Weighted sum</b>	68.38	47.15	13.22	55.48	
	<b>RANK</b>	<b>1</b>	<b>3</b>	<b>4</b>	<b>2</b>	

Decision model with decision tree and decision matrix performs very well in the case of four quarries of Kunda Nordic Tsement, and our model showed that the re-use alternatives already chosen for the quarries (in excavation permits) are optimal for them (water body for Aru-Lõuna, Toolse-Lääne and Mereäärne quarries, and forest in Ubja). So our model supports the already made decisions, but also provides a convinient way to make those decisions in the future, and communicate them to wider audience of stakeholders. Using the model ensures, that the important decisions are made in similar, transparent way, while accounting all the necessary criteria.

Example quarries cover broad scale of variety of quarry types in Estonia (limestone, oil shale, clay) and quarries in HeidelbergCement, while sand and gravel quarries are not represented in this case. Still the model is applicable also to sand and gravel quarries. This model is not applicable for milled peatlands, where environmental conditions and possible reuse alternatives vary and for those areas suitable model (Padur et al. 2017) already exists. So our model could be used to choose reuse alternative for all the quarries in Estonia exept milled peatlands.

To use this model in wider scale in Europe and beyond, some country-specific modifications are probably needed in cooperation with local experts as legislative background and values differ. For example, according to Water Act (§ 33) it is not allowed to create a wetland as a quarry rehabilitation, while creation of wetlands to former quarries is allowed and used in many countries elsewhere. Also in Estonia, large quarries are mainly on state owned land (including all the quarries in this project), while small quarries are on the private land, which creates certain requirements for the quarry reuse (e.g. states preference for reuse alternatives without maintenance costs). In Estonia, self-recovery of the quarries is not allowed, and reuse alternative must be maintained for at least three years according to Estonian Earth Crust Act (2017).

The model needs also some modifications in time, as preferences and therefore weights change (e.g. increasing emphasize on biodiversity and preference of local community). Also some changes in legislation may come up (e.g. allowing self-recovery as a quarry reuse alternative) and therefore the changes should be made to decision-tree. It is possible to add some new criteria to the model if needed, or remove some existing criterion. Also weights could be changed in cooperation with the stakeholders (repeating the survey), or if strong arguments are established to give some additional weight to some specific criteria (e.g. Heidelberg Cement emphasizes the need to have higher weight on biodiversity criteria in the model). Anyway, site-specific preferences of land owner and local municipality should be asked separately during each quarry rehabilitation decision, as well as documents must be considered for green corridors and planning documents crieria.

According to our knowledge, there is no such model done for quarries of mineral resources. Few models done elsewhere (e.g. Soltanmohammadi et al., 2009; Soltanmohammadi et al., 2010; Dal Sasso et al., 2012; Tsolaki-Fiaka et al., 2018) do not incorporate stakeholders to creating the model, or do not have decision-tree to eliminate unimplementable (by legal or environmental reason) reuse alternatives, so there are limitations in their real-life application. Some quarry specific models have been applied in real life (e.g. Bottero et al., 2014). Our model is applicable in real-life decision-making. Using the model ensures, that with every decision all the necessary legal, environmental, socio-economical criteria have been accounted in a uniform and transparent way. This model has also a great importance in communicating quarry rehabilitation decisions to various stakeholders, such as people living near the quarries, so they could have a understanding how such decisions are made.

## 6. Deliverables

Our project delivers following outcome:

- The created model could be directly used in Estonian quarries in Kunda Nordic Tsement and in other sand, gravel, oil-shale, limestone and clay quarries in Estonia;
- Application of the model supported already done decisions about quarry rehabilitation alternative in all four Estonian quarries of Kunda Nordic Tsement — Aru-Lõuna, Toolse-Lääne, Ubja and Mereäärne.

The application of the model is free and is not laborious as only four site-specific comparison criteria values must be found out separately (preferences of land owner and local municipality, planning documents and green network). The approximate time needed to get the values for site-specific criteria and apply the model for the new quarry is one day, additional time must be added for contacting and receiving answers from the land owner and local municipality about their preferences.

The model could be modified and applied elsewhere for choosing optimal quarry rehabilitation alternative, after consultations with the local experts to ensure that differences in legislation have been taken into account and decision tree and comparison model have been modified accordingly. Modifications in the decision tree in cooperation with the stakeholders take about 2-3 days. In other regions, stakeholder survey should also be repeated, as the values of stakeholders could differ between the geographic regions. It will take about five days to prepare the survey and compile the stakeholder contact list, at least month should be given to get a representative sample of stakeholders. Cleaning and analysing the data and modifying the model will take additional five days.

## 7. Final conclusions

In this project we improved the decision making process and developed a multi-criteria decision analysis model for choosing the optimal rehabilitation alternative for quarries. The model consisted of decision tree with restrictive criteria (environmental and legislative) and weighted comparison criteria in decision matrix that brings out the optimal rehabilitation alternative for the quarry. In some cases the only implementable reuse alternative is identified with the decision tree, in other cases decision matrix is used to compare suitable alternatives by taking account environmental (e.g. biodiversity, green network, erosion reduction) and socio-economic (e.g. cultivation and maintenance costs, preference of land owner and local municipality, aesthetic value) criteria, and stakeholders weights for those. We found the optimal rehabilitation alternatives for four quarries of Kunda Nordic Tsement in Estonia – Ubja (oil shale), Aru-Lõuna (limestone), Toolse-Lääne (limestone) and Mereäärne (clay). In all sites, our model supported the already made decisions for quarry reuse, so Ubja should be rehabilitated to forest (alternative also with one of the highest biodiversity estimates) and other three sites to water bodies (based on site-specific values of the restrictive criteria).

Improved decision process supports sustainable land-use and development. The model supports transparent and optimal decision making for quarry reuse, where all the suitable alternatives and necessary criteria have been taken into account in a systematic way. The model is a good basis to communicate quarry rehabilitation decisions to different stakeholders in easily understandable way. As the model is already developed, the further use of the model is easy, relatively fast and does not need very specific knowledge on the topic. The model can be applied in other countries also, but necessary country-specific modifications should be applied in the model. It is also possible to modify comparison criteria weights – for example biodiversity could be more important from the company's perspective. We hope that the model will fasten and help to make the sustainable decisions of the reuse of quarry areas and to give clear understandable arguments in the communication with stakeholders of the quarry rehabilitation in Kunda Nordic Tsement and elsewhere in the Heidelberg Cement group.

To be kept and filled in at the end of your report

Project tags (select all appropriate):

This will be use to classify your project in the project archive (that is also available online)

Project focus:

- ☒ Beyond quarry borders
- ☐ Biodiversity management
- ☒ Cooperation programmes
- ☒ Connecting with local communities
- ☒ Education and Raising awareness
- ☐ Invasive species
- ☒ Landscape management
- ☐ Pollination
- ☒ Rehabilitation & habitat research
- ☒ Scientific research
- ☐ Soil management
- ☐ Species research
- ☐ Student class project
- ☐ Urban ecology
- ☐ Water management

Flora:

- ☐ Trees & shrubs
- ☐ Ferns
- ☐ Flowering plants
- ☐ Fungi
- ☐ Mosses and liverworts

Fauna:

- ☐ Amphibians
- ☐ Birds
- ☐ Insects
- ☐ Fish
- ☐ Mammals
- ☐ Reptiles
- ☐ Other invertebrates
- ☐ Other insects
- ☐ Other species

Habitat:

- ☒ Artificial / cultivated land
- ☐ Cave
- ☐ Coastal
- ☒ Grassland
- ☐ Human settlement
- ☐ Open areas of rocky grounds
- ☒ Recreational areas
- ☐ Sandy and rocky habitat
- ☐ Screes
- ☐ Shrub & groves
- ☐ Soil
- ☐ Wander biotopes
- ☒ Water bodies (flowing, standing)
- ☐ Wetland
- ☒ Woodland

Stakeholders:

- ☒ Authorities
- ☒ Local community
- ☒ NGOs
- ☐ Schools
- ☒ Universities

## Final Project Report: Appendix 1 Tables and Figures

**Table A.1. Overview of the quarries participating in this project**

	Toolse-Lääne	Aru-Lõuna	Mereäärne	Ubja
Mineral resources with average thickness of the layer*	cement LS (11–17 m) construction LS (4 m)	Cement LS (12 m) construction LS (3 m)	Cement clay (31 m)	Oil shale (1.4 m)
Coordinates*	N 59° 26' E 26° 25'	N 59° 26' E 26° 29'	N 59° 30' E 26° 31'	N 59° 24' E 26° 26'
Area (ha)*	227	412	26	152
Proved economic resources (m <sup>3</sup> )*	Cement 23 755 000 Construction 2 556 000	LS: Cement 3 782 450 LS: Construction 7 108 000	7 360 890	2 346 492
Year of establishment**	-	1961	1990	2005
Absolute height on upper layer (m)*	51–52	48–54	0.5–7	64
Absolute height in quarry bottom (m)*	-	36–40.5	–10.5– –14	58.5–60
Potentially economic proved resources	25 Mt of phosphorite	40 Mt of phosphorite	489 000 m <sup>3</sup> of cement clay	120 Mt of phosphorite
Probable potentially economic resources	-	-	-	1 Mt of oil shale
End of excavation permit**	2045	2028/2032	2048	2027
Planned recultivation option**	water body	water body	water body or forest/park	forest

LS- limestone; \* Data from Estonian Land Board (2018); \*\* Data from Estonian Database of Environmental Permits



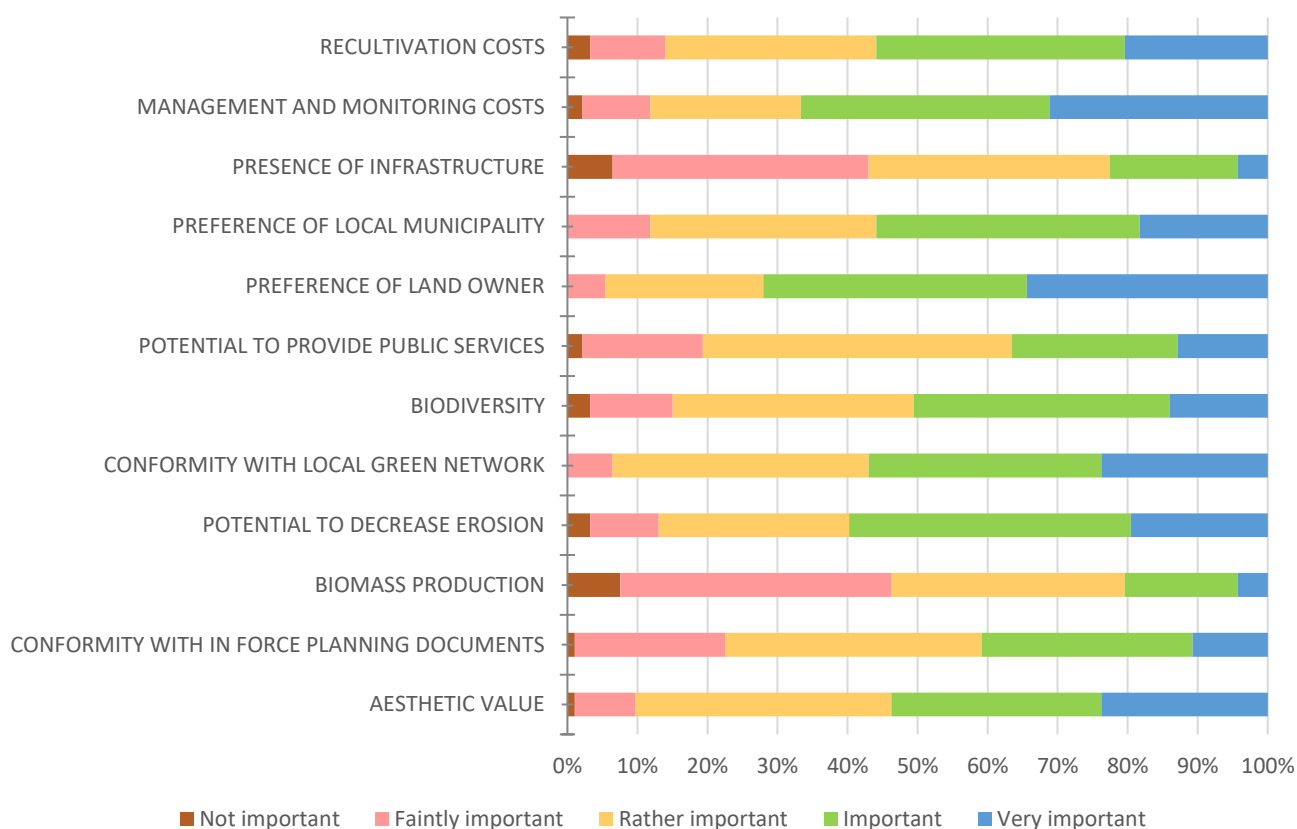
**Table A.2. Questions asked from the stakeholders in the survey.**

Questions asked from stakeholders	Answers
Which stakeholder group do you belong to?	<p>Representatives of:</p> <ul style="list-style-type: none"> <li>• Ministry of Environment, Ministry of Economic Affairs and Communications, Environmental Board (N=11)</li> <li>• Land Board and State Forest Management Centre (N=6)</li> <li>• Local Municipalities (N=26)</li> <li>• Environmental NGOs (N=3)</li> <li>• Companies in the field of environmental management (N=17)</li> <li>• Companies in the field of land resource excavation (N=16)</li> <li>• Scientists in the field of land resource excavation (N=14)</li> </ul>
Do you have any knowledge and/or experiences in the quarry rehabilitation field or have you heard something about it before?	<ul style="list-style-type: none"> <li>• Have not heard anything about it before (N=2);</li> <li>• have heard about it before (N=16);</li> <li>• have the knowledge about the topic (N=29);</li> <li>• have knowledge and experiences of quarry rehabilitation (N=46).</li> <li>• Other (N=0)</li> </ul>
If there are registered probable and/or potentially economic reserves under the proved economic reserve (that is extracted) should it be analysed if it would be reasonable to extract these reserves before the rehabilitation of the area? Please explain your opinion.	<p>open question, answers were divided into:</p> <ul style="list-style-type: none"> <li>• Yes (N=76)</li> <li>• No (N=6)</li> <li>• Yes and No (N=11)</li> </ul>
Please select which of the following criteria may restrict of implementation of some rehabilitation alternative.	<ul style="list-style-type: none"> <li>• Water table height after the reserve is exhausted (N=72);</li> <li>• groundwater depth, if it does not reach to the surface level after the reserve is exhausted (N=38);</li> <li>• habitat of protected species (N=64);</li> <li>• intended purpose of the quarry reuse is determined in the national planning documents (N=39);</li> <li>• permanent maintenance cost of the reuse alternative (N=51);</li> <li>• the demand of some reuse alternatives does not exist (N=39);</li> <li>• other (N=41).</li> </ul>

Please assess the importance of the following comparison criteria.

**Scale:** not important; faintly important; rather important; important; very important.

**Criteria:** recultivation costs, management and monitoring costs, presence of infrastructure, preference of local municipality, preference of land owner, potential to provide public services, biodiversity, conformity with the local green network, potential to decrease erosion, biomass production, conformity with in force planning documents, aesthetic value



Which reuse alternative do you prefer to be implemented on the project site areas after the resources is exhausted?

4 project sites and up to 5 rehabilitation alternatives.

(This question was asked only from local people, who were represented by local municipalities, and landowner, who is the Land Board at these sites.)

**Table A.3. Calculations of criteria values for cultivation and maintenance costs**

Alternative	Cultivation costs	Maintenance costs
Forest	<ul style="list-style-type: none"> <li>Price of seedlings: 0.2-0.3 EUR/seedling (Kekk 2017)</li> <li>1500-2500 seedlings/ha and in pine 3000-5000 seedlings/ha (Rammul et al. 2017)</li> <li>Site preparation costs are about 170 EUR/ha (Kekk 2017)</li> <li>seedling planting costs 0.1-0.2 EUR per seedling (Kekk 2017)</li> </ul> <p>Total: <b>620-2670 EUR/ha.</b></p>	Total: <b>160-240 EUR/ha</b> (Kekk 2017)
Arable land	<ul style="list-style-type: none"> <li>Barley: <b>512 EUR/ha</b> (cheapest)</li> <li>Potato <b>2 596 EUR/ha</b> (most expensive)</li> </ul> <p>(Aamisepp &amp; Persitski 2017)</p>	Same as cultivation costs (Aamisepp & Persitski 2017)
Meadow	<ul style="list-style-type: none"> <li>45 EUR/ha is cost of seeds,</li> <li>175 EUR/ha is fertilizer cost</li> <li>155 EUR/ha (work cost)</li> </ul> <p>Total: <b>375 EUR/ha</b> (Aamisepp &amp; Persitski 2017)</p>	Total (for grazing or haymaking): 154-233 EUR/ha (Aamisepp & Persitski 2017)
Recreational land	<ul style="list-style-type: none"> <li>information boards 320-500 EUR</li> <li>dry toilet 200 EUR</li> <li>covered fireplace and benches 60 EUR</li> <li>bordering for parking lot 1,8 EUR/m</li> <li>staircase/broadwalks 50 EUR/m (Tomson &amp; Kuresoo 2012).</li> <li>Creating recreational infrastructure for recreational area of 322 ha costs about 25 000 EUR (Suurkask 2016)</li> <li>Preparing site for disc-golf (very popular recreational activity in Estonia costs about 70 EUR/ha (tee areas and disc golf bascets).</li> </ul> <p>Total: <b>70-78 EUR/ha</b></p>	<ul style="list-style-type: none"> <li>Site management (cleaning, repairing, provision with firewood and so on) is done twice a week during the summer period and once a month on the winter period (Tomson &amp; Kuresoo 2012)</li> <li>annual management of the 322 ha site is planned 1500 EUR (Suurkask 2016)</li> </ul> <p>Total: <b>5 EUR/ha.</b></p>

**Table A.4. Preferences of land owner and local municipality for the re-use of Ubja quarry**

Alternative	Preference- of land owner	Preference of local municipality
Forest	1	1
Meadow	4	2
Recreational land	3	3
Field	2	4

**Table A.5. Number of species in quarry sites with different applied reclamation option in Europe**

Alternative	Flora	Fauna	Reference
Forest	141 (all plant)	-	(Laarmann et al. 2015)
	27-54 (vascular)	-	(Pensa et al. 2004)
	86 (all plant)		(Trnková et al. 2010)
	15-17 (all plant)		(Celesti-Grapow et al. 2006)
		140 (invertebrate)	(Hendrychová et al. 2012)
Meadow	10-45 (all plant)		(Kirmer et al. 2012)
	69 (all plant)		(Trnková et al. 2010)
	40 (vascular)	16 (invertebrate order)	(Cullen & Wheeler 1994)
	19-53 (all plant)	7-13 (butterfly), 6-16 (carabid), 5-18 (rove beetle)	(Weibull et al. 2003)
	15 (all plant)		(Celesti-Grapow et al. 2006)
Arable land	7-17 (all plant)		(Boutin et al. 2008)
	9-37 (all plant)	3-11 (butterfly), 7-35 (carabid), 2-16 (rove beetle)	(Weibull et al. 2003)
Recreational land		2-7 (mammal) 0-7 (reptilians and amphibians)	(Dickman 1987)
	9-95 (all plant)	4-19 (bird),	(Dallimer 2012)

0-9 (butterfly)

14 (all plant)

(Celesti-Gradow et al.  
2006)

**Table A.6. Average land cover- management factor (C) in different land cover types  
(Panagos et al. 2015)**

Alternative	Average land cover- management factor
Arable land	0,233
Meadows (depending on management)	0,04-0,09
Forest	0,001
Recreational areas (derived for total-non arable land)	0,05



**Table A.7. Average annual plant biomass production (t ha<sup>-1</sup>) in different land cover types**

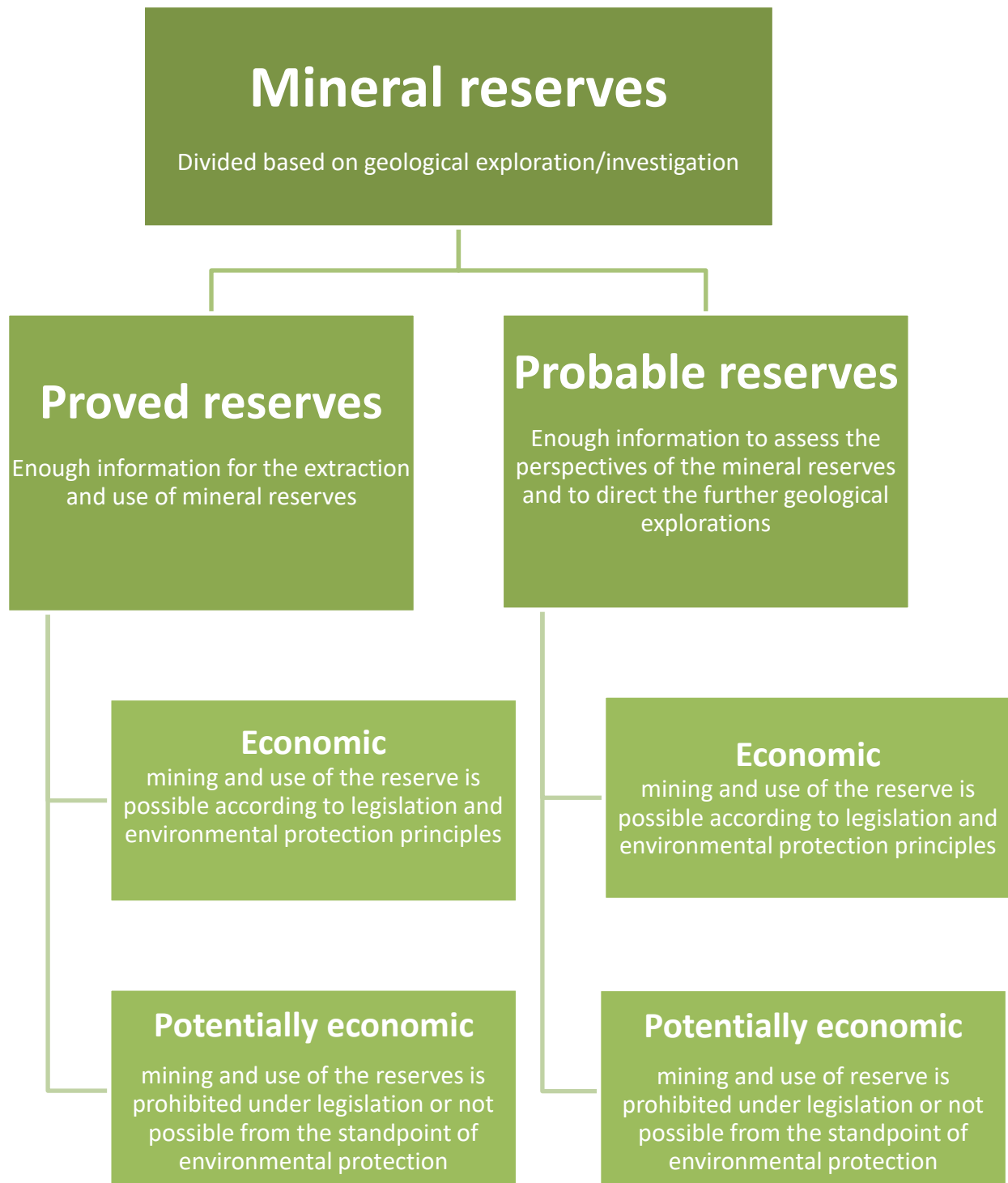
Alternative	Annual plant biomass production (t ha <sup>-1</sup> )	Reference
Forest	21	(Ostonen et al. 2005)
	8	(Gower et al. 2001)*
	2-33	(Waring et al. 1998)*
	6-18	(Schulze et al. 2002)*
	5	(Melillo et al. 1993)*
	8-13	(Tůpek et al. 2010)
Meadow	0,4-1,2	(Kirmer et al. 2012)
	5-7	(Melillo et al. 1993)**
	3-8	(Hector et al. 1999)
	5-17	(Aamissepp & Persitski 2007)
	9	(Haberl et al. 2001)
Arable land	2-45***	(Aamissepp & Persitski 2007)
	2-12	(Christen & Dalgaard 2013)
	10	(Haberl et al. 2001)
Recreational land	6	(Haberl et al. 2001)

\*-to calculate average biomass production (t ha<sup>-1</sup>) from net primary production (g C m<sup>-2</sup>) carbon content of trees (50%) based on Thomas & Martin (2012) was used; \*\*- to calculate average biomass production (t/ha) from net primary production (g C m<sup>-2</sup>) carbon content of herbaceous plant (45%) based on Olson et al. (1983) was used; \*\*\*- depending on cultivated crop, potato biomass production is 30-45 t ha<sup>-1</sup>, while in cereals such as beans, rape, wheat, barley and so on annual biomass production is usually between 2-8 t ha<sup>-1</sup>.

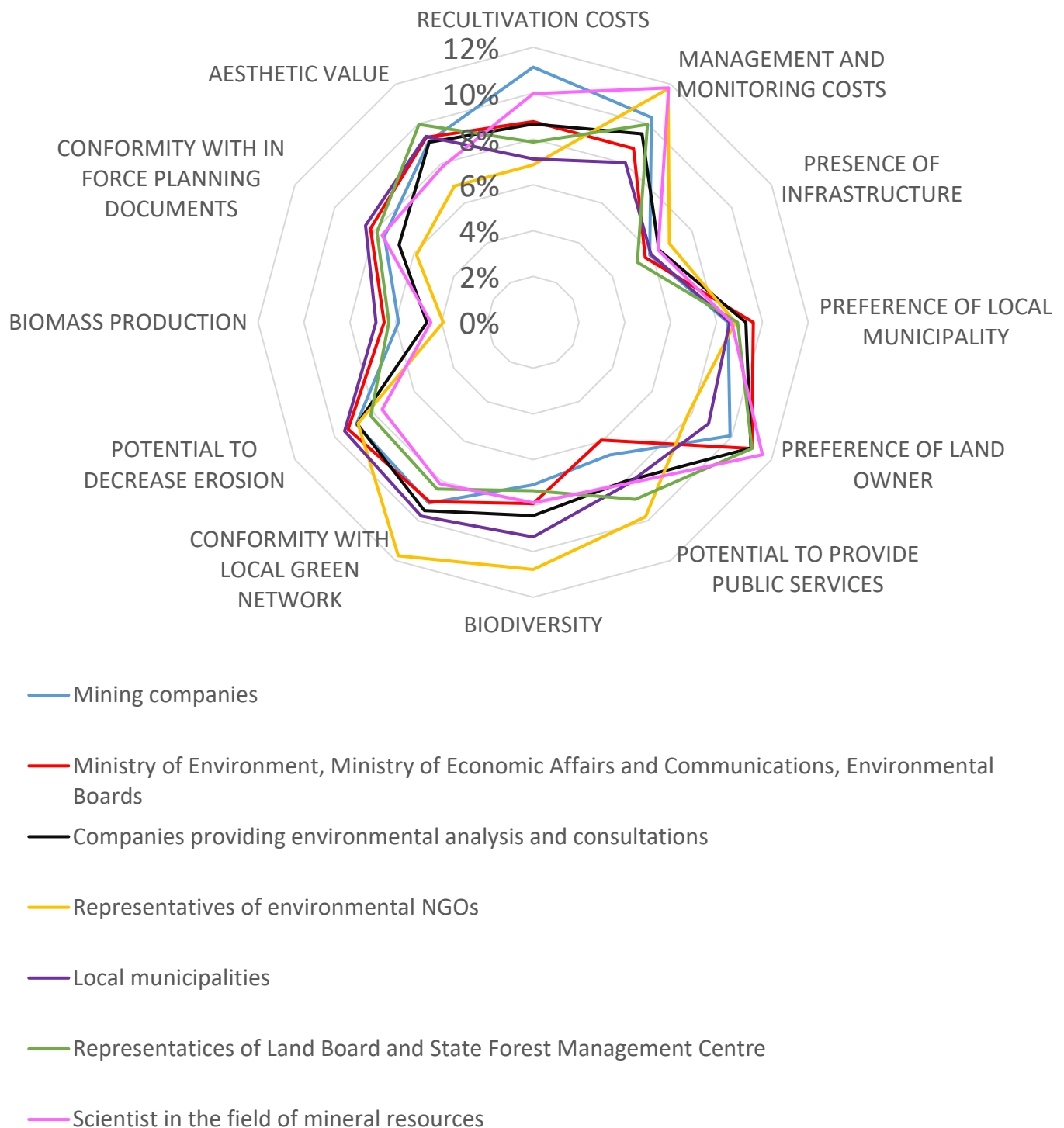
**Figure A.1. Location of quarries of Kunda Nordic Tsement**



**Figure A.2. Categorisation of mineral reserves according to Earth's Crusts Act**



**Figure A.3. Importance of comparison criteria according to stakeholder groups**



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