

Project report: Evaluating reuse options for past peatland extraction sites

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Contents

1	Introduction	2
1.1	Background	2
1.2	Objectives	2
2	Literature review	3
2.1	Social criteria in multi-criteria decision analysis	3
2.2	Decision analysis methods	5
2.3	Stakeholder involvement in decision analysis	6
3	Methods	7
3.1	Decision trees	7
3.2	Weighted linear combination method	14
3.2.1	Criteria value functions	15
3.2.2	SWING Weight elicitation	28
3.3	Pareto optimality	29
3.4	Simplified decision matrix	29
4	Results	29
5	Discussion and Conclusion	32

1 Introduction

1.1 Background

Climate change is a topic of global importance that has seen increasing levels of attention in the sphere of government decision making over the past decades. Many countries, Finland included, have taken steps to reduce their carbon footprint by gradually transitioning away from fossil fuels and towards renewable energy sources. However, the transition away from highly pollutive peat energy, has proven slow. Salomaa et al. [12] describe the peat industry has long traditions in Finland and employs many, making total divestment a divisive topic for many. Finland has nevertheless made a commitment to carbon neutrality by 2035, meaning peat extraction will inevitably cease in many peatlands across the country.

When peat extraction on a site ends, the land becomes the landowner's to use, meaning it is also their responsibility to plan, finance, and implement the peatland's reuse according to Association of Finnish Peat Industries' reuse guide [11]. It is thus important that landowners are provided with information, guidance, and decision making support. The Finnish Environment Institute, as a part of their ongoing project *Systeemihiiili* which aims to promote the use of systems analysis to promote carbon neutral land use, wishes to provide this guidance to landowners and help them select reuse options that are feasible and beneficial to both them and the environment.

1.2 Objectives

The main objective of the project is to support landowners of peatland extraction sites in their decision making by informing them about different reuse options and their potential impacts and benefits. To do this, we develop a decision making tool to compare the different reuse options using Multi-criteria Decision Analysis (MCDA) methods. The tool contains two versions of the decision making process: one a more rigorous process involving multi-attribute value theory (MAVT) to be used by experts in the field, and a simplified version to be used by landowners. The first phase of the decision making in both versions is

to exclude infeasible options using decision trees. The simplified version, instead of giving numerical value to each reuse option with MAVT, presents a decision matrix that indicates whether each reuse option has a positive or negative impact in each criteria. The tool was developed

- to consider the environmental, financial, and social impacts of the different reuse options;
- take into account the user's preferences and priorities regarding the various decision criteria;
- be transparent about the decision making methods and how conclusions are reached;
- be accessible and understandable to users of varying backgrounds.

2 Literature review

The literature review consists primarily of previous applications of Geographic Information System-based Multi-criteria Decision Analysis (GIS-MCDA) in site selection for projects of environmental importance like wind or solar energy farms. Of main interest to us were the social criteria identified for use in the MCDA, the MCDA methods used, and the degree of stakeholder involvement in the MCDA process.

2.1 Social criteria in multi-criteria decision analysis

When selecting sites for projects like solar or wind energy farms or landfills, which have a strong visual impact on the surrounding landscape, the most common consideration when it comes to social impacts seems to be the distance of the site from population centres or otherwise culturally or environmentally important sites. Donevska et al. [4], Harper et al. [6], Suuronen et al. [14], and Özkan et al. [16] all identify distance from population centres as a social criteria in site selection for wind farms, solar energy farms, and landfills. Donevska et al. [4], Suuronen et al. [14], and Özkan et al. [16] also consider nearby

transport infrastructure. Donevska et al. [4] and Suuronen et al. [14] both consider distance or visibility from roads, and Özkan et al. [16] go further by also considering distance to airports, heliports, and railways. In addition to population centres and transport, environmental and cultural sites are also considered. Harper et al. [6] identify distance from natural parks and Natura 2000 sites and Donevska et al. [4], Suuronen et al. [14], and Özkan et al. [16] all consider either distance or visibility from historic, cultural or archaeological sites or landscapes.

By considering the distance from important sites as above, decision makers estimate the negative impact of the project on the local population and possible tourism. Sward et al. [15] describe the possibility of estimating the level of local support for the project, and thus the probability of a site receiving planning permission. To this end, Martinkus et al. [7] describe two metrics for social criteria, which are the number of jobs created and the community assets. The number of jobs created can be evaluated using an economic input-output (EIO) analysis. This analysis is based on known multipliers for different industry sectors that are used to evaluate the effect of constructing a facility. These multipliers can be described utilizing three impacts: direct, indirect and induced. Direct impact includes employment and increased economic activity (e.g. salaries). Indirect impact estimates the direct impacts of connected industries (e.g. mechanics working at a facility). Induced impact describe the spending effect of households that are associated with the direct and indirect impacts. The total effect is calculated as a sum of the three impacts and number of jobs created.

According to Martinkus et al. [7] community assets consist of variables that influence the success of a project, for example the community support and organizational abilities. Martinkus et al. [7] describe three capitals: social, cultural and human. Social capital includes information about social networks in the area, for example the strength, number and types of social networks. Cultural capital is related to innovation and creativity, and therefore, it also refers to the problem solving skills of the community. Human capital refers to the general properties of the community, for example the health, skills and abilities of a community.

These three capitals do not always help the project. For example, Martinkus et al. [7] note that high social capital and low support for the project may lead to the failure of the project if the community uses organizational skills to object against the project. However, in general high level of social, cultural and human capitals promote the success of a project.

Harper et al. [6] identify the social factors that affect the success of onshore wind farms, specifically, by using statistical analysis to identify factors that affect the probability of a site receiving planning permission. Age and education level of local population, and the political affiliation of the local council are included in these social factors according to Harper et al. [6]. Sward et al. [15] consider these to be the characteristics that affect the attitudes towards renewable energy projects. Sward et al. [15] identify these same factors as social criteria in site selection for solar energy farms, also including the prevalence of ethnic and racial minorities, risk perceptions, cultural traditions, way of life, and sense of place of local populations. Sense of place here refers to the level of attachment of the local population to the location and the strength of connection between local identity and place. Sward et al. [15] also identify several socioeconomic criteria, including job creation, income level, public health, and competing land use for the site.

2.2 Decision analysis methods

Sward et al. [15] suggest that GIS-MCDA is often conducted in a specific way. First, the region is examined and literature review and expert consultation is used to form the criteria. These criteria can be divided into two categories, exclusion and decision criteria. The feasible region is formed using the exclusion criteria, and the remaining options are then compared using MCDA. Donevska et al. [4] found that the most common MCDA method when it comes to analysing site suitability for landfills is the weighted linear combination (WLC) method. This involves giving each site a score in each criteria. The criteria are then weighted in terms of importance and the weighted sum of the criteria scores forms the final value of the site. Donevska et al. [4] suggest that various methods exist for determining the criteria weights; most common for landfill site selection are analytic hierarchy process

(AHP) and ratio scale weighting.

One common modification to the WLC method is grouping the criteria into categories before determining weights. Harper, Suuronen, and Caporale all group their decision criteria as a part of the WLC process. Harper et al. [6] group the criteria into categories social acceptability, exclusion zones, and economic viability, whereas Suuronen et al. [14] divide them into social, environmental, and physical criteria. Caporale et al. [3] have the most categories with the criteria divided into aesthetic impact, environmental sustainability, economic sustainability, functional efficiency, noisiness, and inadequacy of institutions. When the criteria are grouped, it is possible to give weights to the criteria within their respective groups and then additionally weight the groups against each other. For example, Suuronen et al. [14] use relative importance weighting (RIW) within the three groups, but then gives each group equal ($\frac{1}{3}$) weights. Caporale et al. [3] use AHP to determine the weights within the categories.

2.3 Stakeholder involvement in decision analysis

The stakeholders of a project are those people and parties who will be involved in or directly affected by the implementation of the project. Sward et al. [15] list that these parties can include government bodies, developers, and local population. Many aspects of these stakeholders' preferences can be considered by including relevant social criteria in the decision analysis. For example, Suuronen et al. [14] incorporate the Ministry of Public Education's restrictions concerning historical sites by including visibility from said sites as one decision criteria. However, according to Sward et al. [15], some social criteria, especially community level social criteria, are more difficult to quantify than others. Thus, they propose including stakeholders in the decision analysis directly by using surveys to assess the viability of specific sites. Marttunen et al. [8] list other methods for involving stakeholders, including interviews, guided workshops, and decision conferencing.

Stakeholder involvement often revolves around eliciting criteria weights. Caporale et al. [3] interviewed wind energy experts and held focus groups with the local population

to determine the relative importance of the decision criteria in their site selection analysis for wind farms. They used the results to define explicit weights. Suuronen et al. [14] used survey results to conduct AHP to define the criteria weights in their site selection analysis for solar energy farms. The survey respondents of Suuronen et al. [14] were mostly local residents, but the survey was also completed by engineers and environmentalists.

Another way to involve stakeholders is to essentially hand the decision analysis over to them by creating a multi-criteria decision support tool. A multi-criteria decision support tool (DST) includes economic, environmental and social metrics to compare different alternatives according to Martinkus et al. [7]. Different weights can then be given to the three metrics so that the effects of the weights on the rankings can be estimated. Allowing the stakeholders to manipulate these weights and evaluate how the rankings change can then help them select the best candidate locations for a more thorough analysis. Martinkus et al. [7] also describe that analyzing different scenarios, such as equal weights or strong social preference, can also be used to evaluate the robustness of decision support tool.

3 Methods

Based on the literature review, prior knowledge of MCDA, and the client's input the following methods are selected for use within the decision making tool.

3.1 Decision trees

In accordance with Padur et al. [9] and their approach to decision making for peatland reuse, the first step in the decision making process is to exclude the infeasible reuse options using decision trees. Decision trees visually represent a set of exclusion criteria that restrict the feasible reuse options based on the characteristics of the peatland in question. Decision trees consist of nodes and branches, labelled with the tested criteria and the criteria values, respectively. Instead of creating one large and complicated decision tree, exclusion criteria and reuse options were categorised to enable the creation of several smaller decision trees:

one primary decision tree that examines only the broader categories and secondary decision trees that examine the reuse options within each category. The reuse options and their categorisation are presented in Table 1. The identified exclusion criteria are primarily gathered from the Association of Finnish Peat Industries' reuse guide [11].

Table 1: Categorisation of reuse options.

Category	Reuse option
Forestry	Pine Downy Birch Silver birch Spruce Alder Mixed forest
Wetland creation	Peatland restoration Aquatic bird habitat Fish farming pond Retention basin
Agriculture	Energy willow Reed Reed canary grass Hemp Turf Cereal Vegetables Herbs Berries
Other reuse options	Recreational area (signposted nature trail) Contingency reserve Biochar/Activated charcoal Wind farm Solar farm Extraction of natural materials (rock, sand, clay, etc.) Natural meadow Wood terminal

The primary decision tree is presented in Figure 1. The exclusion criteria identified concern forestry, agriculture, and wetland creation. Both agriculture and wetland creation require that the peatland be somewhat flat and even. Additionally, wetland creation requires the ability to alter the water table and agriculture requires terrain with average subsoil sediment grain size above 0.06 mm and few or no rocks. Forestation, on the other

hand, cannot be achieved in overly wet conditions according to Aro & Hytönen [1], and therefore forestry is feasible only if the land is sufficiently dry even after its continuous pump drainage ceases along with the peat extraction.

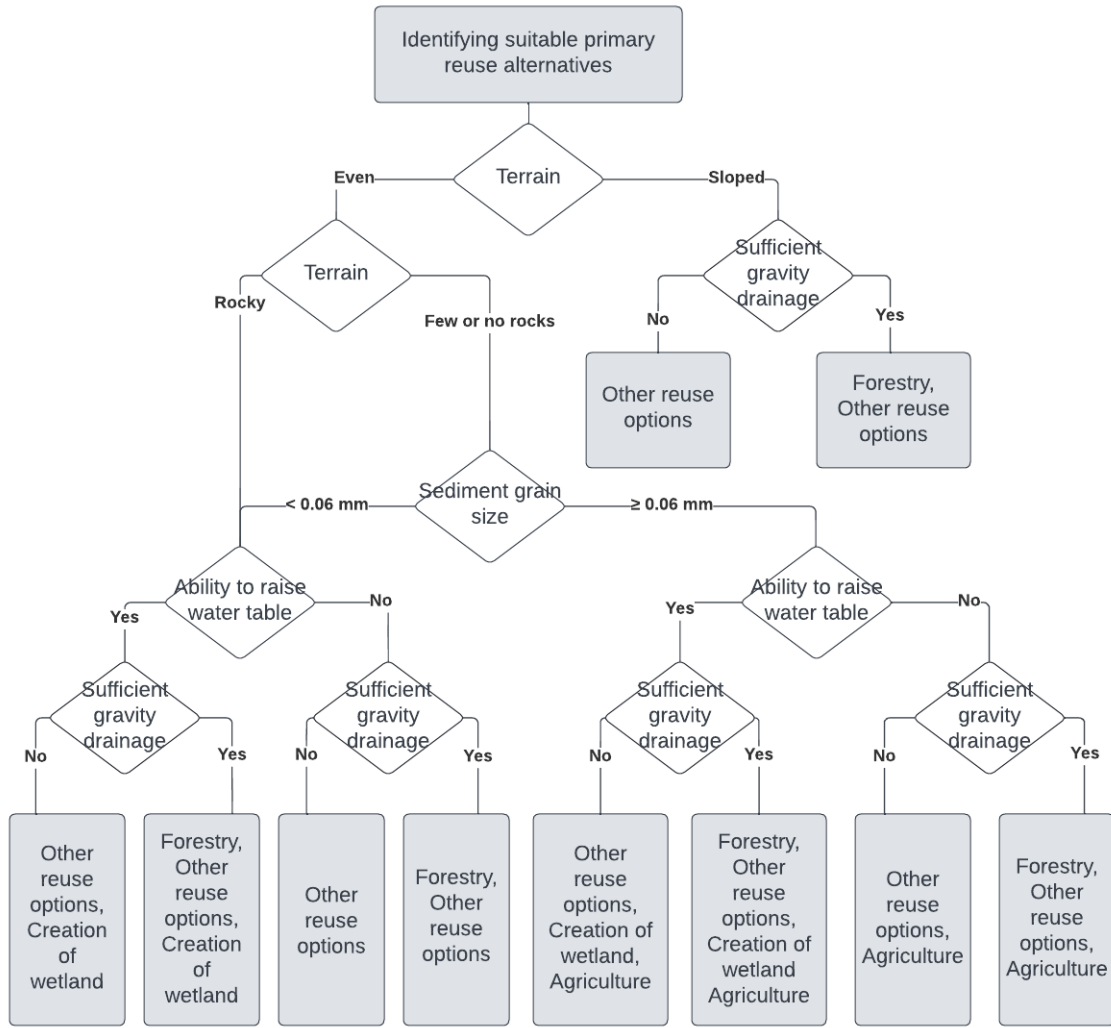


Figure 1: Primary decision tree.

Once the primary decision tree is used to determine which categories of reuse options are feasible, the secondary decision trees are used to identify the feasible reuse options in each feasible category. The forestry decision tree, presented in Figure 2, is based on exclusion criteria concerning sediment grain size and peat layer thickness, which limit the

species of trees that will be successful on the land. The grain size and peat thickness are significant because they together determine the water retention and mineral levels in the ground. Whenever at least two distinct species are feasible, the possibility of a mixed forest also exists. A mixed forest refers to a forest with at least two species of trees and in which the dominant species constitutes less than 75% of the forest's trees.

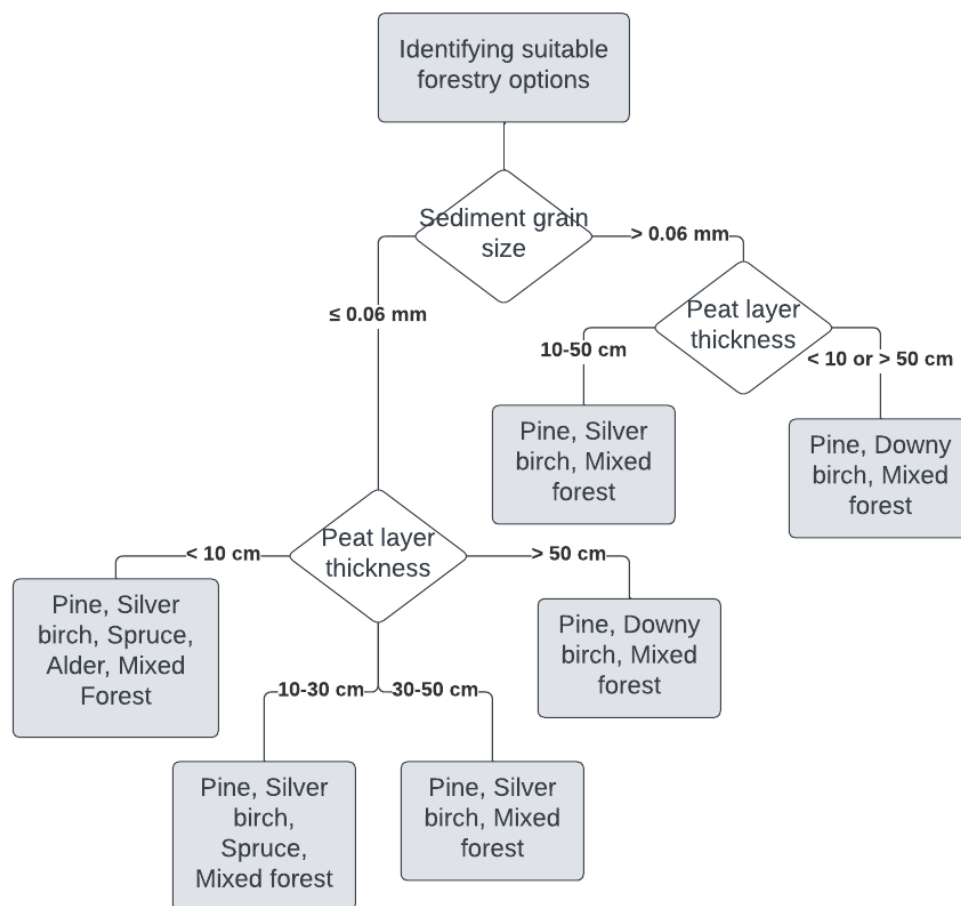


Figure 2: Forestry decision tree.

The wetland decision tree, presented in Figure 3, has three exclusion criteria regarding subsoil pH level, the presence of sulfate soil, and the depth of water the area can potentially retain. The subsoil pH and sulfur concentration are significant as together they can lead to the release of sulfuric acid when oxidised which in turn can cause heavy metals to dissolve

and contaminate surrounding waterways. Subsoil here refers to the layer directly under the peat layer. Water retention is also considered as a sufficient depth is required for fish farming and a functional retention basin. A retention basin here means a large low basin partially occupied by water that serves to retain surplus water during flood events.

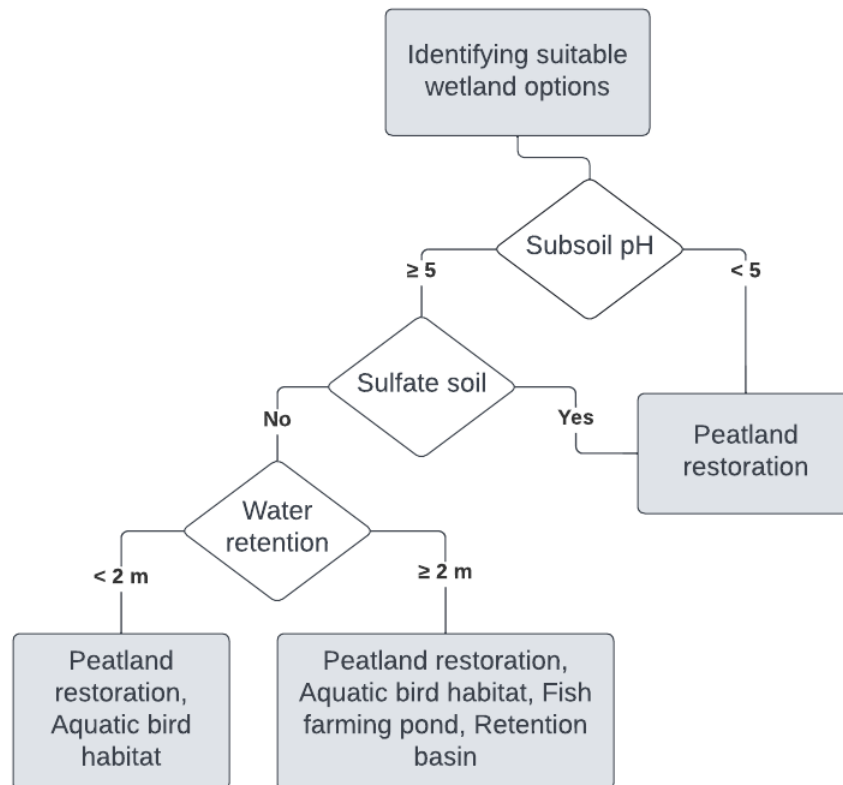


Figure 3: Wetland decision tree.

Presented in Figure 4, the agriculture decision tree, like the wetland decision tree, considers subsoil pH, as certain crops like turf and cereals fare poorly in acidic soils. Cereals also suffer from flooding, so an area with a stable water table is necessary. The last exclusion criteria concerns the distance of the peatland from a power plant. This will potentially exclude bioenergy crops like reed canary grass and energy willow, as their profitability depends partially on the cost of transporting the harvest to the power plant that will utilise the crop.

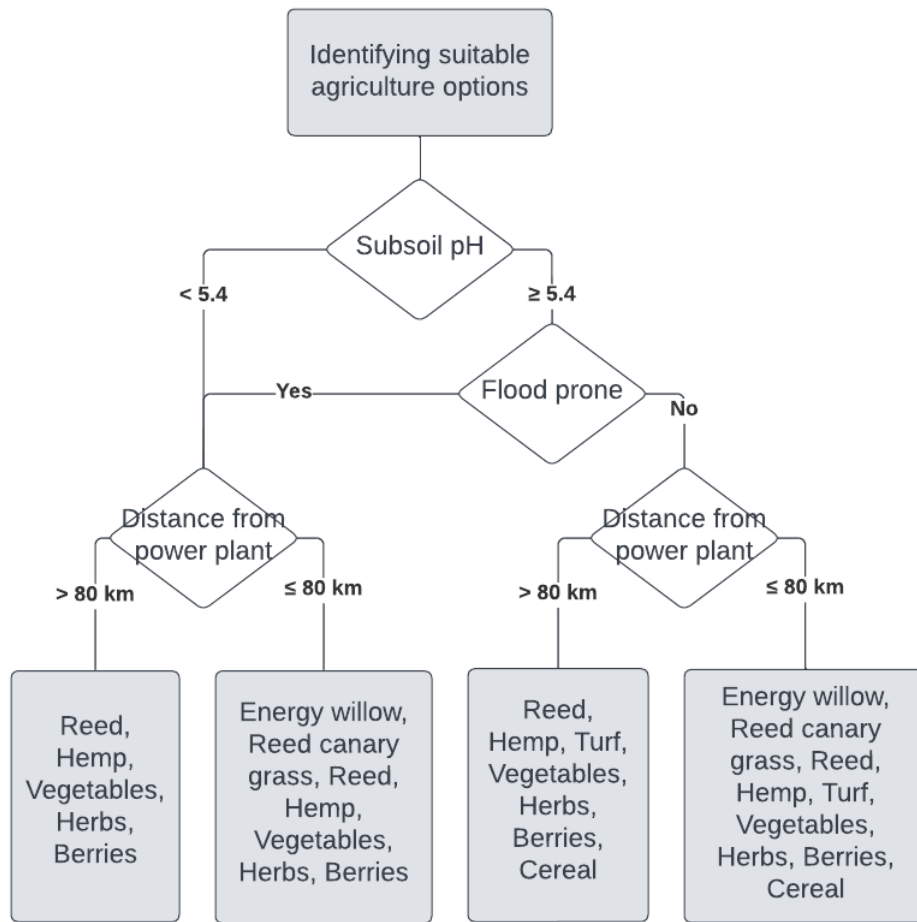


Figure 4: Agriculture decision tree.

Finally, Figure 5 presents the decision tree regarding other reuse options. Only one exclusion criteria is identified, excluding solar and wind energy farms if the site is too far away from the existing power grid.

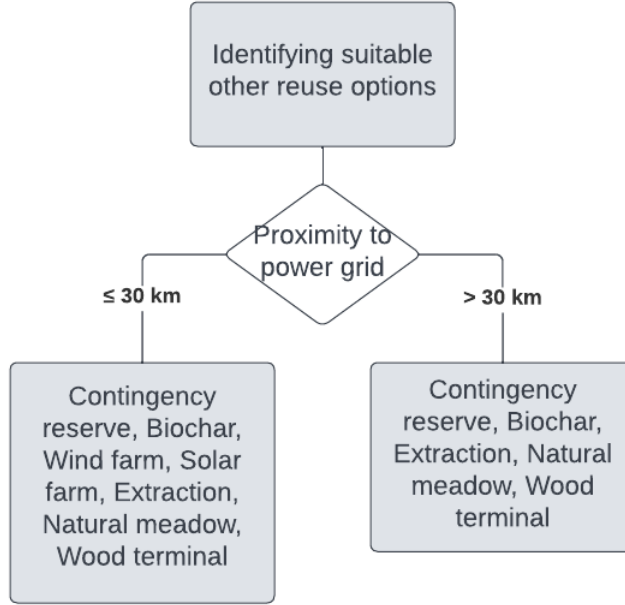


Figure 5: Decision tree for other reuse options.

It is important to note that if a reuse option is determined feasible during the decision tree process, the success of the peatland reuse may still require certain procedures to make the land more suitable. For example, forestry and agriculture options will almost always require fertilisation of the soil, and sites with acidic soil will require liming to neutralise the pH. These procedures come at a cost, and thus will affect the feasibility of the reuse option in some cases. This effect can be captured as part of the cash-flow criteria in the following phases of the MCDA.

3.2 Weighted linear combination method

In the advanced version of the decision making tool, once the infeasible reuse options are excluded, the remaining options are compared using the weighted linear combination method. Given decision criteria $C_1, C_2, \dots, C_n$, each reuse option i has the score

$$S_i = \sum_{j=1}^n w_j v_{ij} = w_1 v_{i1} + w_2 v_{i2} + w_3 v_{i3} + \dots + w_n v_{in},$$

where w_j is the weight for criteria C_j and v_{ij} is the value of reuse option i in criteria C_j , for all $j = 1, 2, \dots, n$ [10]. The criteria weights are defined such that $\sum_{j=1}^n w_j = 1$ and $w_j \geq 0$ for all $j = 1, 2, \dots, n$. The reuse option with the highest score is then the optimal reuse option.

3.2.1 Criteria value functions

To compute the score, the reuse option's value in each criteria must be determined. To this end, value functions for each criteria are defined. Each value function maps a domain of some measurable representation of the given criterion to the real number range 0 to 1. The decision criteria and their categorisation is presented as a value tree in Figure 6.

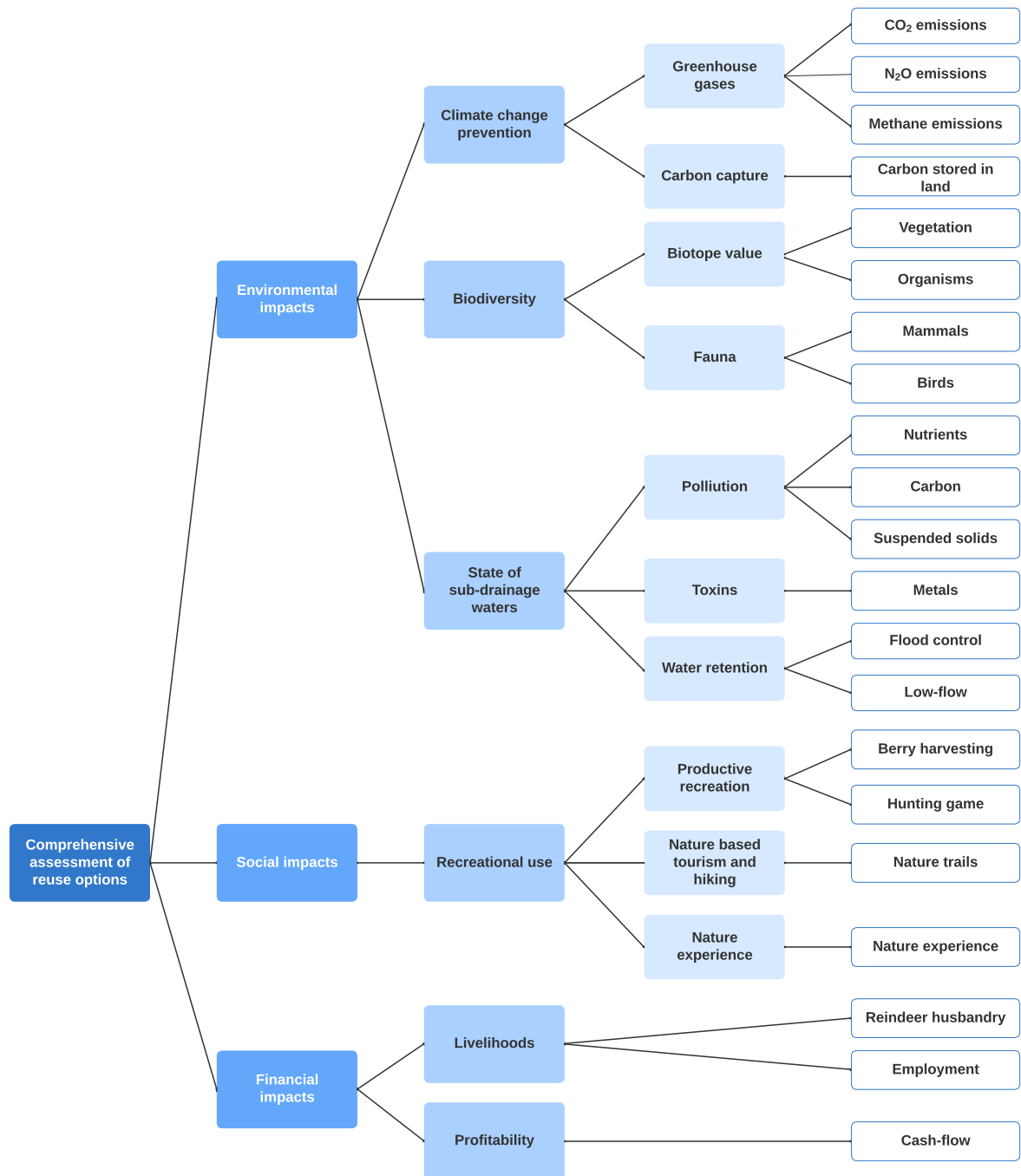


Figure 6: Value tree of decision criteria for evaluating reuse options for peat extraction sites.

CO₂ emissions

This criterion captures impact of the reuse options on CO₂ emissions. The value function is defined categorically in Table 2.

Table 2: Categorical value function for decision criteria CO₂ emissions.

Score	Category	Reuse options
1	Significant positive impact	All forestry options, recreational area, biochar, solar farm, wind farm
$\frac{3}{4}$	Positive impact	Peatland restoration, natural meadow
$\frac{1}{2}$	No impact	Contingency reserve
$\frac{1}{4}$	Negative impact	Remaining wetland options, all agriculture options
0	Significant negative impact	Extraction of natural materials, wood terminal

N₂O emissions

This criterion captures impact of the reuse options on N₂O emissions. The value function is defined categorically in Table 3.

Table 3: Categorical value function for decision criteria N₂O emissions.

Score	Category	Reuse options
1	Significant positive impact	-
$\frac{3}{4}$	Positive impact	-
$\frac{1}{2}$	No impact	All wetland options, Contingency reserve, recreational area, wind farm, solar farm, extraction of natural materials, natural meadow, wood terminal
$\frac{1}{4}$	Negative impact	All forestry options, biochar
0	Significant negative impact	All agriculture options

Methane emissions

This criterion captures impact of the reuse options on methane emissions. The value function is defined categorically in Table 4.

Table 4: Categorical value function for decision criteria Methane emissions.

Score	Category	Reuse options
1	Significant positive impact	-
$\frac{3}{4}$	Positive impact	-
$\frac{1}{2}$	No impact	All forestry options, recreational area, wind farm, solar farm, extraction of natural materials, wood terminal
$\frac{1}{4}$	Negative impact	Aquatic bird habitat, fish farming pond, retention basin, all agriculture options, biochar, natural meadow
0	Significant negative impact	Peatland restoration, contingency reserve

Carbon stored in land

This criterion captures the impact of the reuse option on the amount of carbon stored in the ground. The value function for the criterion is defined categorically in Table 5.

Table 5: Categorical value function for decision criteria Carbon stored in land.

Score	Category	Reuse options
1	Significant positive impact	All forestry options, peatland restoration, contingency reserve
$\frac{3}{4}$	Positive impact	Remaining wetland options, all agriculture options, recreational area, biochar, natural meadow
$\frac{1}{2}$	No impact	Remaining options
$\frac{1}{4}$	Negative impact	-
0	Significant negative impact	-

Vegetation

This criterion captures the biodiversity in vegetation the reuse option can potentially facilitate. The value function for the criterion is defined categorically in Table 6

Table 6: Categorical value function for decision criteria Vegetation.

Score	Category	Reuse options
1	Very high	Natural meadow
$\frac{3}{4}$	High	Mixed forest, aquatic bird habitat, recreational area
$\frac{1}{2}$	Moderate	Birch, downy birch, spruce, alder, peatland restoration, wind farm
$\frac{1}{4}$	Low	Pine, Fish farming pond, retention basin, all agriculture options, contingency reserve, solar farm
0	Very low	All remaining options

Organisms

This criterion captures the biodiversity in organisms the reuse option can potentially facilitate. The value function for the criterion is defined categorically in Table 7.

Table 7: Categorical value function for decision criteria Organisms.

Score	Category	Reuse options
1	Very high	-
$\frac{3}{4}$	High	Spruce, Mixed forest, aquatic bird habitat, recreational area, natural meadow
$\frac{1}{2}$	Moderate	Birch, downy birch, pine, alder, fish farming pond, peatland restoration, energy willow, reed, berries, biochar, wind farm
$\frac{1}{4}$	Low	Retention basin, remaining agriculture options, contingency reserve, solar farm
0	Very low	All remaining options

Mammals

This criterion captures the biodiversity in mammals that the reuse option can potentially facilitate. The value function for the criterion is defined categorically in Table 8.

Table 8: Categorical value function for decision criteria Mammals.

Score	Category	Reuse options
1	Very high	-
$\frac{3}{4}$	High	Spruce, mixed forest, aquatic bird habitat, recreational area, natural meadow
$\frac{1}{2}$	Moderate	Remaining forestry options, energy willow, reed, cereal, biochar, wind farm
$\frac{1}{4}$	Low	Remaining wetland and agriculture options, contingency reserve, solar farm
0	Very low	All remaining options

Birds

This criterion captures the biodiversity in birds the reuse option can potentially facilitate. The value function for the criterion is defined categorically in Table 9.

Table 9: Categorical value function for decision criteria Birds.

Score	Category	Reuse options
1	Very high	Aquatic bird habitat, peatland restoration, reed, recreational area, natural meadow
$\frac{3}{4}$	High	Mixed forest, peatland restoration, reed, recreational area, natural meadow
$\frac{1}{2}$	Moderate	Remaining forestry and wetland options, energy willow, berries
$\frac{1}{4}$	Low	Remaining agriculture options, contingency reserve, biochar, solar farm
0	Very low	All remaining options

Nutrient pollution

This criterion captures the given reuse option's impact on the level of nutrient pollution in surrounding sub-drainage waters. The value function for the criterion is defined categori-

cally in Table 10.

Table 10: Categorical value function for decision criteria Nutrient pollution.

Score	Category	Reuse options
1	Significant positive impact	Aquatic bird habitat, peatland restoration
$\frac{3}{4}$	Positive impact	Retention basin, recreational area, wind farm, solar farm, natural meadow
$\frac{1}{2}$	No impact	Contingency reserve, wood terminal
$\frac{1}{4}$	Negative impact	All forestry options, fish farming pond, extraction of natural materials
0	Significant negative impact	All agriculture options, biochar

Carbon pollution

This criterion captures the given reuse option's impact on the level of carbon pollution in surrounding sub-drainage waters. The value function for the criterion is defined categorically in Table 11.

Table 11: Categorical value function for decision criteria Carbon pollution.

Score	Category	Reuse options
1	Significant positive impact	-
$\frac{3}{4}$	Positive impact	-
$\frac{1}{2}$	No impact	Aquatic bird habitat, fish farming pond, retention basin, recreational area, wind farm, solar farm, natural meadow, wood terminal
$\frac{1}{4}$	Negative impact	Peatland restoration, contingency reserve
0	Significant negative impact	All remaining reuse options

Suspended solids

This criterion captures the given reuse option's impact on the level of suspended solids polluting surrounding sub-drainage waters. The value function for the criterion is defined

categorically in Table 12.

Table 12: Categorical value function for decision criteria Suspended solids.

Score	Category	Reuse options
1	Significant positive impact	Aquatic bird habitat, peatland restoration
$\frac{3}{4}$	Positive impact	All forestry options, retention basin, recreational area, natural meadow
$\frac{1}{2}$	No impact	Fish farming pond, contingency reserve, solar farm, wind farm, natural meadow
$\frac{1}{4}$	Negative impact	All agriculture options, biochar, wood terminal
0	Significant negative impact	Remaining options

Metals

This criterion captures the given reuse option's impact on the level of metals polluting surrounding sub-drainage waters. The value function for the criterion is defined categorically in Table 13.

Table 13: Categorical value function for decision criteria Metals.

Score	Category	Reuse options
1	Significant positive impact	Energy willow, reed canary grass, hemp
$\frac{3}{4}$	Positive impact	All forestry options, natural meadow
$\frac{1}{2}$	No impact	All wetland options, contingency reserve, recreational area, wood terminal
$\frac{1}{4}$	Negative impact	Remaining agriculture options, biochar, wind farm, solar farm
0	Significant negative impact	Extraction of natural materials

Flood control

This criterion captures the potential flood control benefits of the reuse option. The value function for the criterion is defined categorically in Table 14.

Table 14: Categorical value function for decision criteria Flood control.

Score	Category	Reuse options
1	Significant positive impact	Aquatic bird habitat, fish farming pond, retention basin
$\frac{3}{4}$	Positive impact	All forestry options, peatland restoration, contingency reserve
$\frac{1}{2}$	No impact	Remaining reuse options
$\frac{1}{4}$	Negative impact	-
0	Significant negative impact	-

Low-flow

This criterion captures the impact of the reuse option on the occurrence of low-flow in the surrounding water table. The value function for the criterion is defined categorically in Table 15.

Table 15: Categorical value function for decision criteria Low-flow.

Score	Category	Reuse options
1	Significant positive impact	Aquatic bird habitat, fish farming pond
$\frac{3}{4}$	Positive impact	Retention basin, peatland restoration, recreational area
$\frac{1}{2}$	No impact	Contingency reserve, biochar, natural meadow
$\frac{1}{4}$	Negative impact	All forestry and agriculture options, solar farm, wind farm
0	Significant negative impact	Remaining reuse options

Berry picking

This criterion captures the potential of the reuse option to provide opportunity for recreational berry picking. The value function for the criterion is defined categorically in Table 16.

Table 16: Categorical value function for decision criteria Berry picking.

Score	Category	Reuse options
1	Guaranteed	Agriculture: Berries
$\frac{2}{3}$	High potential	All forestry options
$\frac{1}{3}$	Low potential	Peatland restoration, Natural meadow, Wind farm
0	No potential	All remaining reuse options

Hunting game

This criterion captures the potential of the reuse option to provide opportunity for hunting wild game. The potential is captured by estimating the number of Finnish game species that commonly inhabit or visit such a habitat as the reuse option would provide. The criterion value function is defined as

$$v_{16}(x) = \begin{cases} 1 & x \geq 10 \\ \frac{x}{10} & x < 10 \end{cases},$$

where x represents the estimated number of game species. Default estimates for this number are provided for each reuse option in the Excel tool. The estimates are defined using information from the Finnish Wildlife Agency [13].

Nature trails

This criterion captures the potential of the reuse option to provide opportunity for nature trails and hiking. The value function for the criterion is defined categorically in Table 17.

Table 17: Categorical value function for decision criteria Nature trails.

Score	Category	Reuse options
1	Guaranteed	Recreational area
$\frac{1}{2}$	Potential	All forestry options, Peatland restoration, Natural meadow, Wind farm
0	No potential	All remaining reuse options

Nature experience

This criterion captures the nature experience the reuse option can provide. This is captured by evaluating the impact the reuse option would have on the scenic value, cultural value, and spiritual well-being provided by the site. The value function for the criterion is defined categorically in Table 18.

Table 18: Categorical value function for decision criteria Nature experience.

Score	Category	Reuse options
1	Positive impact	All forestry and wetland options, Peatland restoration, Recreational area, Natural meadow
$\frac{1}{2}$	No impact	All agriculture options, Contingency reserve
0	Negative impact	All remaining reuse options

Reindeer husbandry

This criterion captures whether the impact the reuse option has on the potential to facilitate reindeer husbandry. The value function for the criterion is defined categorically in Table 19.

Table 19: Categorical value function for decision criteria Reindeer husbandry.

Score	Category	Reuse options
1	Significant positive impact	All forestry options
$\frac{3}{4}$	Positive impact	Peatland restoration, natural meadow
$\frac{1}{2}$	No impact	All agriculture options
$\frac{1}{4}$	Negative impact	Aquatic bird habitat, contingency reserve, recreational area
0	Significant negative impact	Remaining reuse options

Employment

This criterion captures the labour requirements of a given reuse option. We consider only employment directly created by the reuse options, not any created through a multiplier effect. Any job creation through the reuse option is considered positive so the value function is increasing. The value function for the criterion is defined categorically in Table 20.

Table 20: Categorical value function for decision criteria Employment.

Score	Category	Reuse options
1	Significant long term	Agriculture options excluding reed
$\frac{3}{4}$	Long term	All forestry options, biochar, wind and solar farm, extraction of natural materials, wood terminal
$\frac{1}{2}$	Significant short term	Fish farming pond, reed
$\frac{1}{4}$	Short term	Aquatic bird habitat, retention basin, recreational area
0	None	Remaining reuse options

Cash-flow

Profitability of a reuse option is represented using equivalent annuity approach (EAA). First, the net present value (NPV) is calculated by discounting all future cash flows to present time and summing them:

$$NPV = \sum_{t=0}^n \frac{R_t}{(1+i)^t}$$

where:

i = return that could be earned in alternative investments

t = time period

R_t = cash flow at time period t

n = number of time periods (years in this case).

Next we will derive the EAA formula. We begin by first deriving the present value of recurring cash flows from present to time period n . This is obtained by calculating the difference in present value of infinitely recurring cash flow and the same cash flow discounted from the end of the time period:

$$\begin{aligned} NPV_A &= \frac{A}{i} - \frac{\frac{A}{i}}{(1+i)^n} \\ &= A \cdot \frac{1 - (1+i)^{-n}}{i} \end{aligned}$$

where:

NPV_A = Net present value of annuity

A = recurring cash flow.

Equivalent annuity matches the net present value of the investment the annuity payments. We can obtain the equivalent annuity EAA by substituting reuse option NPV to the annuity formula:

$$\begin{aligned} NPV &= EAA \cdot \frac{1 - (1+i)^{-n}}{i} \\ EAA &= \frac{i \cdot NPV}{1 - (1+i)^{-n}} \end{aligned}$$

While NPV captures the value of the investment decision, it does not take into account the length of the commitment. EAA can be used to compare the profitability of investment options with varying time periods. Comparing just the periodically recurring cash flows is enough as we assume that another equally profitable reuse option (i.e. investment with equal EAA as previously) is available to us after time period n .

3.2.2 SWING Weight elicitation

The weights used to calculate the final score of each reuse option are determined by the user using SWING weight elicitation. With SWING, the user is asked to consider a hypothetical alternative that has the worst possible value in every decision attribute according to Auber et al. [2]. Auber et al. [2] describe that the user can then choose the attribute they deem most important to improve so it is at the best possible value, awarding the chosen attribute non-normalised weight 100. The user must then choose the next attribute to improve it to its best possible level, and assign it a weight between 0 and 100 that reflects the value of this improvement relative to the improvement of the first criteria. This process continues until all attributes are at their best possible level and have been given weights between 0 and 100. These weights can then be normalised to each lie between 0 and 1 and in total sum to 1.

In our case, since the decision criteria are categorised, as illustrated in Figure 6, we reduce the number of direct comparisons that need to be made at once by defining the weights category by category. To further explain the process, we follow one branch of the value tree presented in Figure 6. Consider the three topmost criteria in the value tree: CO₂, N₂O, and methane emissions. These criteria make up the category Greenhouse gases. In the weight elicitation process, these three criteria will thus be compared directly as explained above. However they will not be compared directly with any other criteria. Instead, once the weight comparisons have been made in the greenhouse gases and carbon capture categories separately, the categories will be weighted against each other using the same process, as they together make up the category climate change prevention. This process continues to determine the weighting within the environmental impacts category, and finally the environmental, social, and financial impact categories are weighed against each other. This process does not reduce the number of total comparisons the user must make, but it does mean that the user will need to make no more than three simultaneous direct comparisons at once. The user will also not need to directly compare dissimilar attributes. The approach should thus make the weight elicitation less burdensome if not

less time consuming.

3.3 Pareto optimality

In addition to the decision making framework developed by Padur et al. [9], the advanced version of the tool includes a Pareto optimality check. Fiorenzo et al. [5] define that a Pareto optimal alternative is one such that there exists no other alternative better in one attribute without being inferior in another attribute when comparing alternatives with multiple attributes. Thus, we can disregard reuse options that are not Pareto optimal, as they are options inferior or equal to, in every criteria, at least one other option.

Instead of comparing reuse options on the lowest attribute level, we use the obtained SWING weights and the value tree (Figure 6) to reduce the number of considered attributes. We compare reuse options using scores for environmental, social, and financial impacts.

3.4 Simplified decision matrix

In the simplified version of the tool, the next step after exclusion of infeasible options using decision trees, as described in Section 3.1, is to present a decision matrix expressing the direction of impact of each feasible reuse option in each decision criteria. The direction of impact is represented using colours in the style of a heat map: dark green represents the best possible impact and a dark red the worst possible, with yellow representing a perfectly middling impact of 0.5 and values falling anywhere between these three points determined by the suitable gradient. Infeasible reuse options are marked in black.

4 Results

The finished Excel decision making tool is described in more detail in this section. We describe the tool sheet by sheet.

Instructions

The first sheet contains instructions for the tools use.

Land properties

Land properties are provided as inputs by the user. There are numerical inputs and categorical inputs, which the user selects using drop-down lists. Restricting factors, such as permissions and properties of the surrounding areas, are also listed in this sheet. However, these would have been hard to implement and therefore, the user will have to consider restricting factors separately when evaluating the results.

Users of the simplified version of the tool can skip to the simplified results sheet of the tool after inputting what information they can on this sheet.

Feasible options

Feasibility of each reuse option is estimated using land properties and the decision tree on this sheet. Boolean values are obtained for each reuse option. True value means that the reuse option can be implemented without any major additional requirements, but some cases may still require additional measures to ensure the success of the reuse. False value does not always strictly mean that the reuse option is impossible. However, intensive and costly additional requirements may have to be fulfilled to implement these reuse options.

Reuse options

This sheet contains the attribute values for each reuse option in each criteria as a matrix. Rows represent the criteria and the columns represent the reuse options. Reuse options that have been determined infeasible are marked with red. There are two values for each reuse option: the default attribute value and user input. If the user does not provide an input, the default value will be used for calculating the value of the reuse option. A scale of measurement is also defined for each criteria and displayed in the second column of

the sheet. The scales on this sheet have not yet been normalised to the 0-1 real number scale for ease of understanding and input. The default attribute values are as described in Section 3.2.1.

Value function elicitation

Value functions are formed in value function elicitation sheet. Lower and upper limits, m and M respectively, are provided for each attribute so that user inputs can be mapped into value between 0 and 1. The general formula for these maps is

$$v(x) = \begin{cases} 1 & x \geq M \\ \frac{x-m}{M-m} & m < x < M \\ 0 & x \leq m. \end{cases}$$

The resulting values are displayed in a decision matrix.

Simplified results

This sheet contains a two heat-map style decision matrices. One as described in Section 3.4 and another displaying only the third level categorisation of decision criteria; climate change prevention, biodiversity, state of sub-drainage waters, recreational use, livelihoods, and profitability; on the horizontal axis instead of each individual criterion. In this matrix the reuse options are also categorised into forestry, wetland creation, and agriculture instead of listing each individual option in the category. The other reuse options are given as usual.

Weighting

The user gives weights to the attributes in this sheet. All subcategories are weighted separately. The weights are elicited using SWING weighting as described in Section 3.2.2.

Weight calculations

This sheet displays the normalised weights as well as the normalised scores of each reuse options in each criteria. Below this the sheet displays the final score of each reuse option, whether they are feasible, and whether they are Pareto optimal. The value distribution of the final score over the environmental, social, and financial criteria is also displayed for each reuse option.

Results

On this final sheet of the tool the results of the MCDA are presented. The results are visualised several different ways. First, the scores of each reuse option are presented as a list, as well as whether the reuse option is feasible. Then an ordered list is presented where the top 10 reuse options are ranked based on their scores. Aside from these lists, the results are also displayed as a stacked bar chart and with scatter plots. The stacked bar chart presents the top 10 reuse options, their scores, and how that score distributes over environmental, social, and financial impacts. There are three scatter plots which plot the scores of the reuse options in environmental, social, and financial criteria against each other pairwise.

5 Discussion and Conclusion

Our final tool is influenced and inspired by the approach presented by Padur et al. [9], and the structure of the tool is consistent with that. Like Padur et al. [9], we first use decision trees to exclude infeasible options and only then is the comparison of the reuse options using decision criteria considered. However, because we consider more reuse options and define them more specifically than Padur et al. [9], our set of exclusion criteria is more extensive and thus we have several decision trees, unlike the single one presented by Padur et al. [9]. On the other hand, our tool considers roughly the same number of decision criteria as Padur et al. [9], many of which are similar to criteria used by Padur et al. [9].

Our decision criteria are also categorised into environmental, social, and economic criteria, similarly to Padur et al. [9]. We found this type of categorisation common in applications of MCDA to site selection problems of environmental importance, as described in Section 2.2.

Contrary to Padur et al. [9] who define the weights for the decision criteria by surveying a variety of stakeholders, our tool allows each user to define their own weights. SWING, the weight elicitation method used, also differs from Padur’s approach. In fact, SWING was not commonly mentioned in the literature, but in addition to being used in MCDA by the Finnish Environment Institute previously, it is simple to implement while still offering relatively rigorous results. Our choice of the weighted linear combination method, on the other hand, was influenced by the literature as it is very common in site selection applications. Padur et al. [9] does not describe the MCDA method following the decision tree and weight elicitation phases.

The tool is completely functional but we were not able to test the tool with real site data. Therefore, some features of the tool could most likely be improved. User feedback would be valuable for evaluating which parts of the tool could be modified to be more convenient to the user. In addition, some attribute values could be imprecise because there are many categorical value functions. There may be too few categories, which makes it difficult to correctly represent differences between attribute values. There are also many rating scales and therefore, the tool may be prone to bias in the results. However, the tool is a good framework and the default values can be modified by the Finnish Environment Institute. In addition to simply modifying the default values, the tool can easily facilitate a change from a categorical variable to a continuous variable in the event that more precise information about the attribute values in each reuse option is found. For example, the emissions related criteria could be measured in annually emitted grams per square metre and the employment criteria in man-hours. Other modifications to the tool are possible as well: the addition of new exclusion criteria in the decision tree phase is feasible and relatively simple, and adding new reuse options or decision criteria is possible but may be laborious due to the nature of Excel.

Overall, the tool is a good framework for the decision making process which can easily be refined further by the Finnish Environment Institute should they choose to implement the use of more precise attribute values. The tool also fulfills the objectives stated in Section 1.2. The set of decision criteria does cover environmental, financial, and social impacts; the user has full freedom to define the criteria weights according their preferences; and the nature of Excel is such that the calculations for each step of the process are clearly visible, and thus transparent to those who wish to investigate the process in detail. The last objective regarding accessibility and clarity for users of varying backgrounds is subjective, but although the Excel tool is visually number-intensive, especially in the sheets containing mid-process calculations, we believe that the results are stated in a clear enough manner that anyone can understand the main conclusions of decision analysis.

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Self-assessment

There were two main changes in the scope of the project from what was initially described in the project plan. Firstly, the tool was created to have two different decision making processes: a simplified version that supplies results directly after the decision tree phase, and a more rigorous one that includes defining attribute values and weights for the decision criteria. In practice, this means that users of the simplified method can skip to the simplified results sheet of the Excel tool after filling out the first one. The second change in scope is that we did not test the tool with any real site data, as was initially planned. This was due to time restraints, as the tool was not fully functional early enough for us to finish the report and also test the tool before the deadline.

Two main factors contributed to this issue with time. Between the submission of the project plan and the interim report our initial project leader chose to drop out of the course and the project. Very little progress was made during the time surrounding that decision due to lack of leadership and sufficient communication, so although we were able to choose a new project leader and refocus we arrived at the interim report slightly behind schedule: we had not defined all the decision criteria nor the attribute values for each reuse option in each criterion. In addition, as we began to work on this task in earnest after the interim presentations, it proved a very time consuming task. We initially aimed to have precise estimates in each attribute value, using appropriate units of measurement like grams per square metre or man-hours depending on the criterion. However, this information was hard to come by for many of reuse options and criteria, and eventually we had to settle for categorical variables for most criteria.

This use of categorical variables is perhaps the tool's weakest point. As mentioned in Section 5, with the categorical variables, the attribute values used in the MCDA are less precise than with continuous variables, leading to less variation between the scores of the reuse options in each criterion and ultimately, results that do not capture reality as accurately as possible. Additionally, the value functions, which transform the attribute values to a score on a scale from 0 to 1, are all linear in the tool, which is a simplifying

assumption that further limits how accurately the results represent reality. However, as mentioned in the conclusion, the attribute values can easily be changed in the tool if the Finnish Environment Institute wanted to implement the use of more precise continuous variables, and even altering the value functions to non-linear functions should be relatively simple, should it be deemed necessary.

In hindsight, the research and definition of precise attribute values of each reuse option in each criteria was not a realistic task or the best use of our time. If these attribute values had been defined by experts we could have devoted more time to value function elicitation and other aspects of the Excel tool. In general the project could have benefited from more cooperation with experts in various field relating to peatland reuse. On our part this would have required better planning and time management, as well as better communication with the client.