Marttunen, Mika; Haara, Arto; Hjerppe, Turo; Kurttila, Mikko; Liesiö, Juuso; Mustajoki, Jyri; Saarikoski, Heli; Tolvanen, Anne

Parallel and comparative use of three multicriteria decision support methods in an environmental portfolio problem

Published in:
European Journal of Operational Research

DOI:
10.1016/j.ejor.2022.09.007

Published: 01/06/2023

Document Version
Publisher's PDF, also known as Version of record

Please cite the original version:
Marttunen, M., Haara, A., Hjerppe, T., Kurttila, M., Liesiö, J., Mustajoki, J., Saarikoski, H., & Tolvanen, A. (2023). Parallel and comparative use of three multicriteria decision support methods in an environmental portfolio problem. *European Journal of Operational Research*, *307*(2), 842-859. https://doi.org/10.1016/j.ejor.2022.09.007

European Journal of Operational Research 307 (2023) 842–859

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Innovative Applications of O.R.

Parallel and comparative use of three multicriteria decision support methods in an environmental portfolio problem

Mika Marttunen[a,*], Arto Haara[b], Turo Hjerppe[a], Mikko Kurttila[b], Juuso Liesiö[c], Jyri Mustajoki[a], Heli Saarikoski[a], Anne Tolvanen[d]

[a] SYKE, Finnish Environment Institute, Latokartanonkaari 11, Helsinki 00790, Finland
[b] Luke, Natural Resources Institute Finland, Yliopistokatu 6 B, Joensuu 80100, Finland
[c] Aalto University, Ekonominaukio 1, Espoo 02150, Finland
[d] Luke, Natural Resources Institute Finland, Paavo Havaksen tie 3, Oulu 90570, Finland

ARTICLE INFO

Article history:
Received 12 February 2021
Accepted 7 September 2022
Available online 10 September 2022

Keywords:
Decision support systems
Behavioural operational research
Multiple criteria analysis
Stakeholder involvement
Portfolio decision analysis

ABSTRACT

Environmental management problems are often portfolio problems where the task is to find a set of actions that meets different objectives (e.g., the reduction of greenhouse gas emissions) and constraints (e.g., costs). We report experiences from deploying multiple operations research (OR) methods in a real decision-making setting and discuss the insights gained from this process. The applied methods were Multi-Attribute Value Theory (MAVT), the project portfolio selection tool Your Own Decision Aid (YODA) and Robust Portfolio Modelling (RPM). The methods were applied in a portfolio case evaluating three peatland rewetting options ("No action", "Restoration", "Damming") for 79 drained peatland stands in an important recreational and nature conservation area in southern Finland. The pros and cons of the methods were evaluated, as well as their key methodological challenges, in a participatory environmental portfolio case. The applied methods yielded similar results in terms of the superiority of rewetting options. The strength of MAVT was its ability to highlight the strengths and weaknesses of all three rewetting options for a single peatland stand. YODA's strength was its simplicity and the possibility to apply it independently via the Internet. RPM made it possible to determine the priority of peatland stands within constraints, even without precise preference information. To our knowledge, this is the first systematic evaluation of three methods representing different 'method categories' (MAVT, multi-criteria elimination, portfolio decision analysis) applied to a real environmental problem.

1. Introduction

Environmental decision-making situations are complex and contested and finding widely acceptable solutions requires a good overall understanding of the ecological, economic and social impacts, as well as the relationships within and among them. Often, the problems involve trade-offs between conflicting goals and the task is to find a set of actions that meet the objectives of the various stakeholders and/or the specific targets (e.g., CO_2 emission reduction) and constraints (e.g., costs). Multi-criteria methods are a powerful approach for dealing with trade-off situations and supporting participatory land use planning and natural resource management (e.g., Turkelboom et al. 2018, Kurttila et al. 2020).

However, the choice of an appropriate multi-criteria method is not straightforward. Different methods have both strengths and weaknesses, and their applicability depends on the characteristics of the decision-making problem, as well as the practical constraints, such as available resources (e.g., Al-Shemmeri et al. 1997, Marttunen et al. 2015). To aid the selection of a method, several authors have proposed conceptual frameworks (e.g., Al-Shemmeri et al. 1997, Guitouni and Martel 1998, de Montis et al. 2004, Kurka and Blackwood 2013, Guarini et al. 2018, Watróbski et al. 2019, Cinelli et al. 2020, Salabun et al. 2020). Failure to identify the appropriate method may place the resulting analysis at risk and greatly diminish the relevance of the results.

It is also possible to utilise multiple methods in an application, and several approaches exist for implementing the combined use of multiple methods (Mingers and Brocklesby 1997; Kotiadis and Mingers 2006; Belton and Stewart 2010). The main distinctions between these different combinations are whether more than one methodology is used, whether the methodologies used come

* Corresponding author.
E-mail address: mika.marttunen@syke.fi (M. Marttunen).

https://doi.org/10.1016/j.ejor.2022.09.007

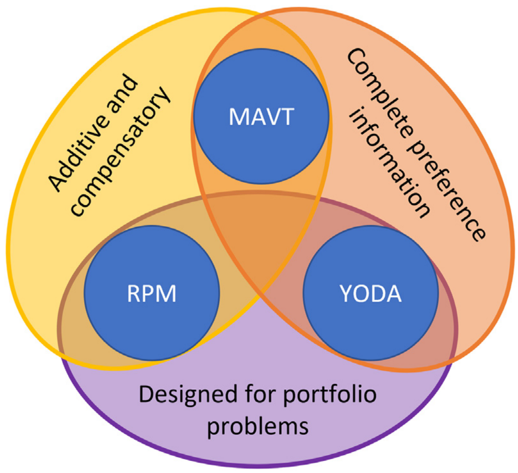


Fig. 1. Selection of the methods for the comparison based on different dimensions of the methods.

from the same or from different paradigms, whether the methods are used sequentially, in parallel or in interplay, and whether the methodologies are used as a whole or certain parts of them are taken out and combined (Marttunen et al., 2017).

Previous comparative research indicates that different methods (e.g., using different weighting techniques) can lead to different results (e.g., Buede and Maxwell, 1995). Furthermore, there is evidence that disagreements between methods become more significant and important as the number of alternatives and criteria increases (Hobbs and Horn, 1997). Indeed, it has been suggested that applying more than one method will give more reliable results in the ranking of the decision alternatives (Hobbs and Horn, 1997). If the methods produce different results, identifying the reasons for the differences may help to better understand the sensitivity of the results and the factors that affect the outcome (Hobbs and Horn, 1997).

Despite these intuitively appealing arguments on the potential benefits of applying multiple methods to support decision making and problem solving, only a few empirical studies have analysed whether these benefits can be realised in actual applications or if the added complexity of multimethod decision support actually outweighs these benefits (Marttunen et al., 2017). Our study addresses this research gap by utilising a real-life decision support setting with multiple decision objectives that are pursued through a combination of actions (a portfolio) rather than through selecting one out of a few mutually exclusive decision alternatives.

In this paper, we analyse the complementary application of three different decision support methods in a portfolio case related to the possible rewetting of 79 drained peatland stands in an important recreational and nature conservation area in the City of Tampere, southern Finland. The methods were Multi-Attribute Value Theory (MAVT), the project portfolio selection tool Your Own Decision Aid (YODA) and Robust Portfolio Modelling (RPM). These methods were selected because they differ in terms of their ability to use incomplete preference information, the approach used to combine criteria-wise values of the alternatives (additive/compensatory vs. not) and the focus on portfolio problems (Fig. 1).

MAVT is a widely used, relatively simple MCDA (Multi-Criteria Decision Analysis) method (e.g., Huang et al. 2011, Cegan et al. 2017) and hence largely applied in participatory processes (e.g., Marttunen et al. 2015). In contrast to the other two methods, it is not specifically designed for portfolio problems, but for all types of multi-criteria decision situations. However, it can be applied to calculate the benefits of the projects that are selected to the portfolio according to their benefit-to-cost ratios (Phillips and Bana e Costa, 2007).

RPM is specifically designed to solve portfolio decision problems and it also enables the use of incomplete preference information (Liesiö et al., 2007). It is particularly appropriate for supporting multi-stakeholder processes, as it helps to identify areas of agreement while leaving flexibility for negotiation (Baker et al., 2020).

YODA complements the two other methods because, in contrast to them, it does not add up the criteria-wise values of the alternatives or allow poor performance in one criterion to be compensated by good performance in others. Furthermore, YODA is regarded as a promising method for portfolio decision situations where transparency and ease of adopting the method are needed (Kurttila et al., 2020). It is also applicable to participatory processes, but further testing is needed to gain a better understanding of its full potential in supporting stakeholder involvement.

Our research questions are as follows: (i) Do the three decision support methods yield similar results regarding the best rewetting options for different types of peatland stands and what are the reasons for possible differences? (ii) How do stakeholders perceive the different methods when they are applied jointly? (iii) What is the added value and what are the requirements of each method for supporting the environmental portfolio case? (iv) What are the key challenges in their application? Based on the analysis, we discuss the benefits of jointly applying these methods and draw conclusions on their possible combinations in portfolio decision problems.

In addition to reporting the parallel use of different multi-criteria methods in a novel application area, this paper also contributes to the growing literature on behavioural operations research that seeks to investigate the behavioural aspects related to the use of operation research (OR) methods to support problem solving and decision making (Hämäläinen, 2015; Montibeller and von Winterfeldt, 2015; Marttunen et al., 2017). In particular, we report experiences from deploying multiple OR methods in a real decision-making setting and discuss the insights gained from this process. We also discuss the benefits and challenges in applying multiple methods simultaneously based on our reflection, as well as the verbal and numerical feedback we received from the engaged stakeholders.

2. Methods

In the following sections, we describe the basic principles of the three applied decision support methods. A comparison of the methods in terms of their theoretical and practical requirements and aspects is presented in Table 1.

2.1. Multi-attribute value theory

Multi-Attribute Value Theory (MAVT) is an MCDA approach that combines factual data about the criteria-wise performances of the alternatives with subjective value judgments about the trade-offs between the criteria (Keeney et al., 1993). As a result, the model produces commensurate performance values for the alternatives, reflecting their 'goodness' for a stakeholder having certain preferences over the criteria. There are various ways to assign the weights to criteria (Riabacke et al., 2012). They can be asked directly from the stakeholders or by using some more sophisticated technique, such as Swing (von Winterfeldt and Edwards, 1986) or SMART (Edwards and Barron, 1994). Preference elicitation can be carried out, for example, in structured interviews with stakeholders representing different interest groups (Marttunen and Hämäläinen, 2008) or in a workshop (or decision conference; Phillips and Phillips, 1993) facilitated by a decision analyst. The performances

Table 1
Comparison of the three applied decision support methods in terms of their theoretical and technical requirements and aspects.

	MAVT (Keeney et al. 1993)	**YODA (Kurttila et al. 2020)**	**RPM (Liesiö et al. 2007)**
Theoretical background	Based on the axiomatic decision theory (Keeney and Raiffa, 1993); long research tradition (40+ years).	New pragmatic approach based on the definition of acceptance thresholds for all decision criteria.	Preference model based on the axiomatic decision theory. Incomplete preference information is captured through sets of feasible parameter values.
Assumptions / simplifications	Deploys an additive value function, which assumes mutually preference-independent attributes and that at least one attribute is difference independent (for details, see Keeney et al. 1993, Dyer and Sarin 1979).	Non-compensatory; a small deviation from the boundaries for a criterion may lead to the rejection of an action, even if it is otherwise a good one.	RPM uses an additive-linear portfolio value function, which requires additional preference assumptions in addition to those required by the additive value function (for details, see Golabi et al. 1981, Liesiö 2014).
Input data needs	Performance of alternatives, criteria weights, shape of criterion-specific value functions.	Performance of actions, acceptance thresholds, constraints for the portfolio.	Performance of actions, (incompletely defined) criteria weights, shape of criterion-specific value functions, portfolio constraints.
Methodological constraints in portfolio analysis	Produces ranking order of alternatives, but not the best portfolio.	May not produce an efficient portfolio.	No major constraints, allows a variety of different types of information to be added to the model.
Software implementation of the method	Various software packages available (Mustajoki and Marttunen, 2017). Can be implemented in Excel.	Tailored YODA software available online (yoda.luke.fi).	Windows-based RPM-Decisions software available (http://rpm.aalto.fi/rpm-software.html)

of the alternatives in terms of each criterion are obtained, for example, through field measurements, mathematical modelling or expert evaluation. Under certain assumptions (see, e.g., Keeney et al. 1993, Dyer and Sarin 1979), an additive model can then be applied to obtain the overall performance values for each alternative by multiplying its criterion-wise performance scores with corresponding criteria weights and then summing them.

The results of MAVT can be analysed and presented in various ways. They can, for example, be aggregated into so-called group preferences reflecting the average or common opinion of the group (e.g., Belton and Pictet 1997). However, as it is often the case that the average does not represent the preferences of any group member, a more fruitful approach can be a disaggregated one in which different stakeholders' results are compared in a workshop with the aim of understanding the other stakeholders' preferences and the reasoning behind different perspectives (e.g., Belton and Pictet 1997). Consequently, this type of structured analysis of the various perspectives of stakeholders can enhance understanding of the problem as a whole and open up the policy discourse (Saarikoski et al., 2013). MAVT can also be used as a means to support deliberation in these processes (Gregory et al., 2012), as well as the process of learning and discovery.

In portfolio cases, MAVT can be applied so that in the first step, the performance of each possible action is evaluated separately. In the next step, portfolio optimisation is used to select the most efficient portfolio (as described in the next section). Alternatively, one can use an intuitive, approximate approach, in which actions are added one-by-one to the portfolio according to their benefit–cost ratio until the resource constraint is reached (see, e.g., Phillips and Bana e Costa 2007, Clemen and Smith 2009).

2.2. Portfolio decision analysis and robust portfolio modelling

Portfolio decision analysis (PDA; Salo et al. 2011, Lahtinen et al. 2017, Liesiö et al. 2021) is family of models, tools and practices that seek to support portfolio decisions in which the goal is to select a subset of available decision alternatives (e.g., projects, investments or actions). This contrasts with the standard decision analysis setting, where one out of a list of mutually exclusive alternatives is selected. Due to the combinatorial nature of portfolio decision problems, PDA models usually consist of two elements: The first element is a decision analytic model (based on, e.g., an MAVT value function) that captures decision makers' preferences regarding multiple attributes and uncertainties, and outputs the overall values (or utilities) of portfolios. The second element is an optimisation model that captures portfolio (e.g., resource) constraints and logical dependencies between project decisions. Solving this model with appropriate mathematical programming techniques identifies the feasible portfolio that yields the highest value (or utility).

The main advantage of PDA is that it helps to consider a comprehensive set of actions and is not restricted to a small number of alternatives constructed unaided by stakeholders. Recent applications of PDA in environmental management include the designing of nature conservation area networks (Bicknell et al., 2017), prioritisation of eradication actions for invasive species (Helmstedt et al., 2016) and siting of an offshore wind farm under environmental objectives (Cranmer et al., 2018).

Robust Portfolio Modelling (RPM) is a PDA method that allows incomplete information about the importance of criteria, the criterion-specific performance levels of actions, the costs of actions and the magnitude of interactions among the actions (Fig. 2, Liesiö et al., 2007; Fliedner and Liesiö, 2016). RPM is based on MAVT: it utilises a linear-additive portfolio value function (Golabi et al., 1981, see also Liesiö 2014, Liesiö and Vilkkumaa 2021), in which the value of a portfolio is the sum of those projects' multi-attribute values that the portfolio contains. RPM uses a tailored multi-objective optimisation algorithm to solve all efficient portfolios. For instance, in the case of incomplete information on criterion weights, a feasible portfolio is efficient if no other feasible portfolio yields a higher or equal value for all allowed weights and strictly higher for some (for a more general definition of efficiency, see Liesiö et al. 2008). The set of efficient portfolios can be used to identify which actions are robust choices and on which actions further information acquisition efforts should be focused. For each action, a core index value is calculated, indicating the share of efficient portfolios in which the action is included. Core indices are used to identify (i) which actions are included in all efficient portfolios (core actions, green squares in Fig. 2), (ii) which actions are not included in any efficient portfolios (exterior actions, red squares in Fig. 2) and (iii) which actions are in some but not all efficient portfolios (borderline actions, yellow squares in Fig. 2).

2.3. Project portfolio selection tool, YODA

The YODA tool is based on the application of a voting method and interactive visualisation technique (Hiltunen et al., 2009, Kurttila et al., 2020). The fundamental aim is to promote finding a commonly acceptable project portfolio instead of a mathemat-

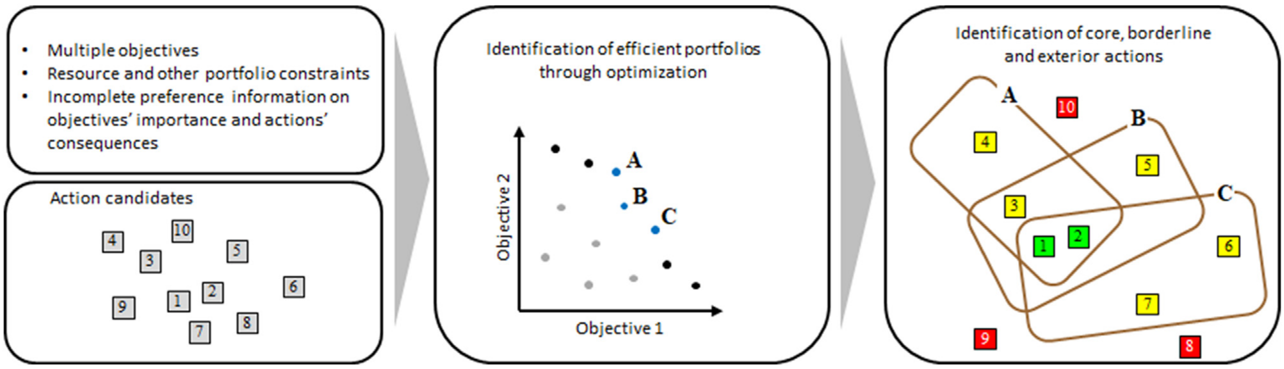


Fig. 2. Illustration of the RPM method.

ically optimal project portfolio (Kurttila et al., 2020). Originally, the tool was developed to support the selection of a single decision alternative (Hiltunen et al., 2009). In this selection, it utilises decision makers' acceptance thresholds for decision criteria as an instrument of preference, and only those actions whose performance meets this threshold requirement are included in the portfolio. Contrary to MAVT and RPM, YODA does not utilise criterion weights to aggregate performance criteria. Instead, the participants define through YODA's visual user interface the acceptance thresholds for each decision criterion, and in this way they accept or reject alternatives and decrease/increase the feasible set of choices.

YODA is interactive in the sense that it requests the individual user to continue the acceptance threshold definition until a unanimous result (when only one acceptable decision alternative should be identified) or a project portfolio that is feasible with respect to the portfolio-level constraints is achieved. When applied to project portfolio selection problems with several decision makers, YODA also applies concepts from RPM (Liesiö et al., 2007) by, for example, allocating projects to different classes based on how many decision makers have accepted them on their portfolios. The classification used in the case is presented in 5.3. A more detailed description of the phases of YODA in a portfolio decision problem is provided in Supplementary material A1.3.

2.4. Case study and action-research approaches

The comparative application of methods with practitioners in an actual decision-making situation poses major challenges for research to assess the usability of methods and to identify good practices. Therefore, we applied both case study (CS) and action-research (AR) approaches (Montibeller et al,. 2009). CS is a research approach for generating an in-depth, multi-faceted understanding of a complex issue in its real-life context (Crowe et al., 2011). AR is a research strategy that permits the systematic investigation of an issue while aiming to improve organisational practices. It has been advocated as an appropriate method for studying MCDA interventions, which could support organisations' decision-making (Montibeller et al. 2009).

The CS and AR approaches can both be criticised for providing little basis for generalisation (Blichfeldt and Andersen, 2006). However, the CS method was well-suited to our study with the aim to closely examine the applicability of different decision support methods and their synergies in a real-life context (see Yin, 1984). The AR approach allowed us to work with the practitioners and understand the possibilities and limitations of the methods from their perspectives, and also build their capacities to use the methods in the future.

To ensure systematic collection and analysis of the case study data, we used following methods when collecting information on the participants' opinions and attitudes:

- Observation of discussions in the first workshop by all authors.
- Tape-recorded discussions in the small groups in the second workshop.
- Structured questionnaires at the end of both workshops.
- Triangulation using transcribed small-group discussion data, participant observation data and quantitative questionnaire data.

3. Case study description

The Kintulammi area (total area 608.5 hectares), located in the City of Tampere (population 241 000) in southern Finland, is regionally and nationally an important nature protection and recreational area. It consists of a wide variety of forests, peatlands, rock outcrops, lakes and small waters. Of the peatlands, which cover one-fifth of the area, approximately 100 hectares were drained for forestry circa 50–70 years ago, which has resulted in a decrease in their biodiversity and recreational values.

In 2020, the City of Tampere developed a management plan for the Kintulammi area. An important part of the plan was to make recommendations for the rewetting of the area's forestry-drained peatlands over the next five years. The key questions were which peatlands should be rewetted first and by what measures to maximise the biodiversity benefits and minimise the potential problems caused by greenhouse gas (GHG) emissions and nutrient loading to waters. Peatlands can be a source or sink of GHGs, depending on how they are managed (Laine et al.. 2019), and rewetting can cause at least short-term nutrient loading to watercourses (Koskinen et al.. 2017; Tolvanen et al., 2020a). An important aspect in the management plan was the mitigation of climate change, which in peatlands may be in trade-off with biodiversity protection (Juutinen et al., 2020). In the City of Tampere's climate strategy, a target was set to reduce the GHG emissions to 40% of the 1990 levels by 2030. Therefore, an interesting and also a key trade-off question was how to improve the biodiversity of the area's peatlands without causing a significant increase in GHG emissions.

The premises for the application of the methods were good. First, there was a good knowledge base regarding the predicted impacts of rewetting options arising from previously developed models and existing expert assessments (Saarimaa et al., 2019; Tolvanen et al., 2020b, c). Second, the City of Tampere had recognised the need for a more systematic and participatory evaluation of alternatives due to the complex nature of the decision situation. From a research perspective, the case presented an ideal complex portfolio problem with several incommensurable criteria and con-

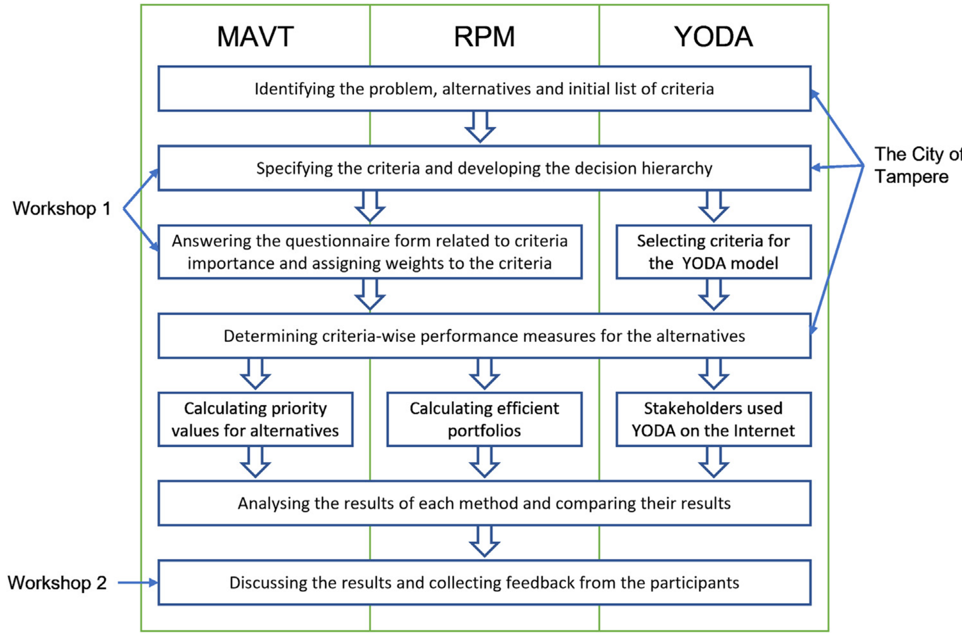


Fig. 3. The main phases in the parallel use of the three decision support methods in the case.

flicting objectives, such as biodiversity, GHGs, recreational use and water quality.

4. Implementation of the methods

In the following, we first describe the phases in the implementation of the methods, starting from the phases that were common to all methods. We then present the specific features of the application of each method. A more detailed description of the use of each method is given in Supplementary material A1.

4.1. Phases in the use of the decision support methods

The three decision support methods were applied in parallel. Some of the phases were common to all, while others were method specific (Fig. 3). Common phases were the definition of the criteria, indicators and alternatives, as well as their performance evaluation. The most significant differences were the type of preference information that needed to be elicited, the use of this information and the nature of stakeholder involvement. The process of collecting feedback from the participants was identical for all three methods.

4.2. Phases common to all methods

4.2.1. Identification of the problem and alternatives

The problem itself, identification of the best rewetting option for each peatland stand and their order of priority, was given by the City of Tampere. The alternative rewetting options (“No action”, “Restoration”, “Damming”) to be implemented in each peatland stand were based on a previous study (Tolvanen et al., 2020b). Peatland restoration requires quite substantial measures, in which drainage ditches are filled using excavators and trees are cut and transported from the restored site (e.g., Tolvanen et al. 2020a). Damming is a new method that has not been commonly applied in Finland. In the City of Tampere, “Damming” was proposed as an alternative option since it can be carried out using voluntary manual work and thus provides opportunities for citizens to participate and educate themselves about nature conservation work.

Our task was the framing of the spatial scale of the decision alternatives. We ended up with a scale in which the decision alternatives comprised 79 peatland stands, the area of which varied from 0.01 to 15.59 hectares (median 0.93 hectares). The division into stands was based on the site fertility and tree stand structure, so that each stand formed a uniform unit of analysis within a peatland or a forest. The stand division did not take hydrology into account, although in practice, neighbouring peatland stands are commonly part of the same peatland pool and hence under the same hydrological impact. Nevertheless, each stand was a separate unit in our assessment and could be targeted with any of the three rewetting options, independent of its neighbour.

4.2.2. Engagement of stakeholders

The decision support methods were applied in a participatory way: interaction with stakeholders took place in two workshops with 13 stakeholders in the first one and 10 in the second. Most of the participants were from different departments of the City of Tampere who were responsible for developing the management plan for the recreational area. In addition, there were participants from the Centre for Economic Development, Transport and the Environment, the Finnish Association for Nature Conservation and the company responsible for the recreational infrastructure of the area.

In the first workshop (4 February 2020), a set of criteria for evaluating management options developed by the research team, as well as the effects of the management options on these criteria, were presented and discussed. Thereafter, the participants were asked to complete a questionnaire and estimate the significance of the impacts of the alternative rewetting options on each criterion. In the second workshop (12 March 2020), the results from the three different decision support methods were presented in a plenary session, followed by facilitated break-out groups (one for each method) to obtain feedback from participants on the usefulness of the methods and the understandability of the results. At the end of each workshop, the participants were asked to complete a brief feedback questionnaire.

4.2.3. Determining the decision criteria

Most of the decision criteria were based on a previous study by Juutinen et al. (2020), which had been tailored to the management

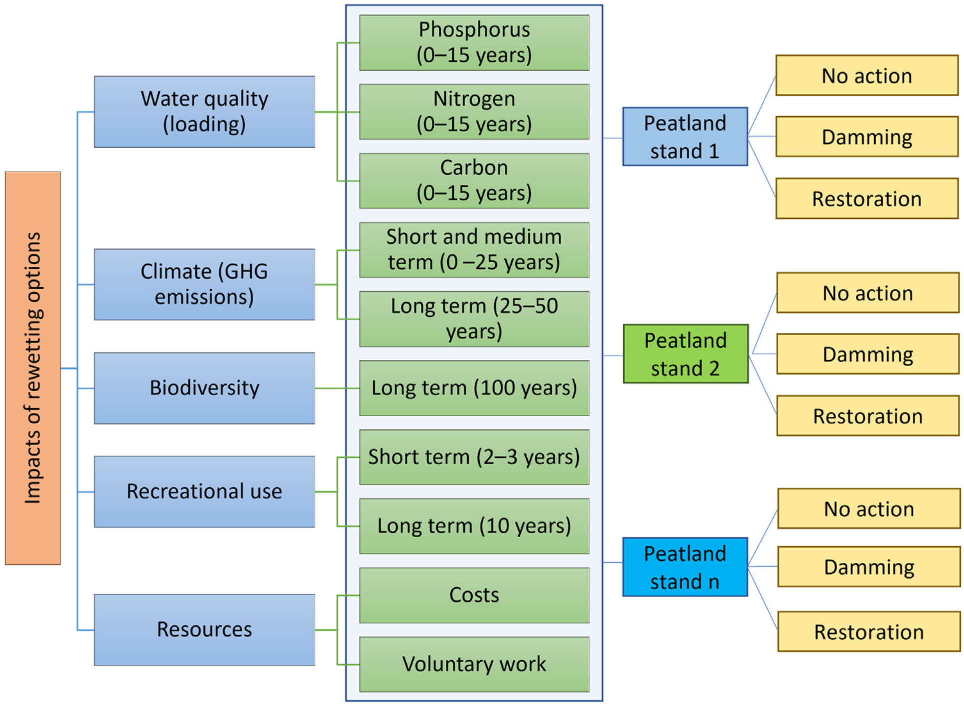


Fig. 4. The decision hierarchy used in the evaluation of rewetting options.

plan of the City of Tampere (Tolvanen et al., 2020b). Following discussions within the research group and with stakeholders in the first workshop, recreational use and volunteer work were included in the hierarchy as new criteria. As the time horizon of the impact assessment was very long (50–100 years) and the effects of the measures were expected to change over time, both short-term and long-term effects were considered in the analysis. The temporal dimensions varied by criterion depending on the length of time required to stabilise the effects of rewetting options. The applied decision hierarchy is presented in Fig. 4.

In YODA, we did not use all the criteria mentioned in Table 2. The two water quality criteria (nitrogen and carbon) and resources criteria (costs and voluntary work) were excluded from YODA, because they were considered of minor importance in Workshop 1, and because the visualisation and definition of threshold levels for a large number of criteria would have been cognitively very demanding. This is due to fact that in YODA it is not possible to arrange the criteria into a hierarchy in which thresholds could be assigned to higher-level criteria consisting of multiple lower-level criteria. In MAVT, the criteria are organised into a hierarchy (i.e., a value tree) in which, for instance, water quality includes three sub-criteria: phosphorus, nitrogen and carbon. Thus, in MAVT it is more natural to consider various sub-criteria of water quality compared to YODA, in which it was reasonable to only include the most important water quality criterion (i.e. phosphorus). Phosphorus is a good indicator for loading as the rewetting options which have high phosphorus loading have also high nitrogen and carbon loading.

4.3. Phases specific to each method

4.3.1. Application of MAVT

The weights for the criteria were derived from the questionnaire that was completed in the first workshop. In the questionnaire, the respondents were asked to assign 100 points to the criterion for which they considered the difference between the worst and best management options to be the most significant. Then, they were asked to assign fewer points to the other criteria to reflect the significance of the difference between the worst and best management options in these criteria compared to the most significant one. The final weights of the criteria were obtained by normalising the sum of the assigned points to one. One should note that the criteria-wise values of the options were scaled so that "No action" received a baseline value of 0 for each criterion and "Damming" and "Restoration" received positive or negative values, depending on how they compared to "No action". In this way, we were able to ensure an explicit consideration of the incremental benefit or decremental disadvantage of these options compared to doing nothing (see Clemen and Smith 2009).

Determining the weights of the criteria is a central task in MAVT and RPM, and it is prone to various errors and biases (Montibeller and von Winterfeldt, 2015). In order to ensure the focus of participants on the magnitudes of and differences in the impacts of the options, it is important to describe the impacts and their ranges in a comprehensible way. Otherwise, there is a risk that the weights assigned to the criteria will reflect the participants' 'general' values regarding these criteria rather than in this particular context. Consequently, this may lead to an exaggeration of minor effects or a reduction of significant effects and therefore distort the outcome. In describing the impacts of the alternatives in the questionnaire, we paid attention to this issue and tried to proportion the impacts in an understandable way. For example, for water quality impacts, we described the effects as follows: "In total, the nutrient load from the peatland stands from the study area currently causes about 10% of the phosphorus, nitrogen and humus load in the catchment. The annual nutrient load can increase at most sevenfold compared to a situation where nothing is done."

As a result of MAVT, we obtained 13 different weightings for the criteria, reflecting the preferences of each workshop participant, and consequently 13 preference orders for the rewetting options for each peatland stand. From these, we formed various types of visualisations, such as a figure illustrating the share of the best-ranked rewetting options among the respondents for each peatland stand, and a figure showing the overall values of each rewetting

Table 2
Criteria used in the evaluation of rewetting options.

Criterion	Description	Methods that used the criterion
Water quality (loading)[1]	Change in total loading to surface waters as phosphorus, nitrogen and organic carbon from the peatland stand over the 15-year reference period (kg/ha).	All methods
Climate (GHG balances)[1]	GHG balances per hectare from the soil ((CO_2), methane, nitrous oxide) in CO_2 equivalent tons per hectare compared to a no action situation. Two time periods: the first 25 years after the rewetting option and the following 25 years (years 26–50).	All methods
Biodiversity[1]	Predicted long-term (100 years) change in the number of peatland plant species for which the habitat is favourable. Plants were used as an indicator of biodiversity.	All methods
Conditions for recreational use[2]	Current conditions for recreational use (Scale: 0 = No recreational value to 10 = Very considerable recreational values).	YODA
Change in recreational use[2]	Estimated change in the recreational use in different rewetting options (Scale: -4 = Very negative effects to 4 = Very positive effects). Two time periods: 2–3 years (short term) and 30 years (long term) from the baseline compared to a no action situation.	Short-term impacts: all methods;
long-term impacts: MAVT and RPM		
Costs[3]	Estimated costs of the rewetting if carried out as a purchase service (€/hectare).	MAVT, RPM
Volunteer work[4]	Opportunities for voluntary work (hours/hectare).	MAVT, RPM
Peatland stand area	Area of the peatland stand (hectares).	YODA
Peatland area	Total area of restored peatland stands during the next ten years (25 hectares was set as the target level).	YODA, RPM

[1] Based on the previous scenario assessment in the area (Tolvanen et al., 2020b).
[2] Based on expert evaluation by the City of Tampere.
[3] Based on cost estimates in Tolvanen et al. (2013) and Aalto and Aalto (2018). "Restoration" was expected to be carried out using machinery and manual damming.
[4] Based on the expert opinions of the research team. "Damming" has a much smaller workload than "Restoration", and the work can also be carried out as voluntary work, which is in principle free of charge. Some stakeholders thought that voluntary working hours could also be seen as a positive opportunity to engage citizens in environmental work.

option for each peatland stand for three exemplary stakeholder profiles. We also created an Excel workbook for use by the City of Tampere planners, which allows an analysis of the overall priority values of the different rewetting options for any selected peatland stand and for any weight profile (either given freely or selected from those assigned by the 13 workshop participants).

A more detailed description of MAVT and its use in a portfolio decision problem is given in Supplementary material A1.1.

4.3.2. Application of RPM

The RPM model was built on top of the additive multi-attribute value function assessed in the MAVT method. The value of a portfolio was modelled as the sum of the multi-attribute values of those options that were included in the portfolio. A single portfolio size constraint was specified to capture the client's objective of selecting at most 25 hectares in total for "Restoration" or "Damming" in the first phase. In addition, a total of 79 linear constraints were needed to ensure that a portfolio could not include both "Restoration" and "Damming" options for any single area.

Before the second workshop, efficient portfolios were identified without any preference information on the importance of the attributes (i.e., all non-negative weights that sum up to one were considered feasible). In the workshop, this fostered 'what-if' analysis, i.e., what the set of efficient portfolios would look like for a specific ranking of the attributes' importance suggested by the participants. To complement such interactive analysis, we also produced results based on the average attribute weights across 13 weightings assessed by the participants of the first workshop. Although these weights were initially assigned for the MAVT analysis, these could also be applied in RPM, as RPM is based on the same axiomatic foundations as MAVT. In addition, the ability of RPM to incorporate incomplete preference information was utilised here to allow the weight of each top-level attribute to vary by ±30% from the average point-estimate values.

4.3.3. Application of YODA

In the first workshop, the YODA method and the selection process were introduced to the participants by using a YODA task example. After the first workshop, two YODA selection tasks, namely the selection of peatland stands for either "Restoration" or "Damming", were sent via email to 13 stakeholders. Each stakeholder received their personal username and password for YODA to carry out their tasks independently.

In both tasks, the stakeholders defined personal acceptance thresholds for criteria they considered important based on their own preferences. The selection criteria captured the changes that the different rewetting options would lead to in biodiversity, loading to surface waters, soil GHG balances and conditions for recreational use. The goal in both tasks was to choose peatland stands including a total of 25 hectares for "Restoration" or "Damming", depending on the task.

Altogether, nine stakeholders carried out both tasks. A few days after the opening of the YODA task, a feedback questionnaire was sent to all participants, in which the applicability and usefulness of YODA were inquired, as well as the pros and cons and suggestions for improvement of YODA. In the second workshop, the combined results of the YODA selection tasks from the respondents were introduced to the participants and the inclusion and exclusion of individual peatland stands from the combined solution was reviewed together with all participants. The application of the YODA model is described in more detail in Supplementary material A1.1.

5. Results

5.1. MAVT

The opinions of the participants regarding the weights of the criteria varied quite considerably, although many of them had a similar, nature-oriented perspective (Supplementary material

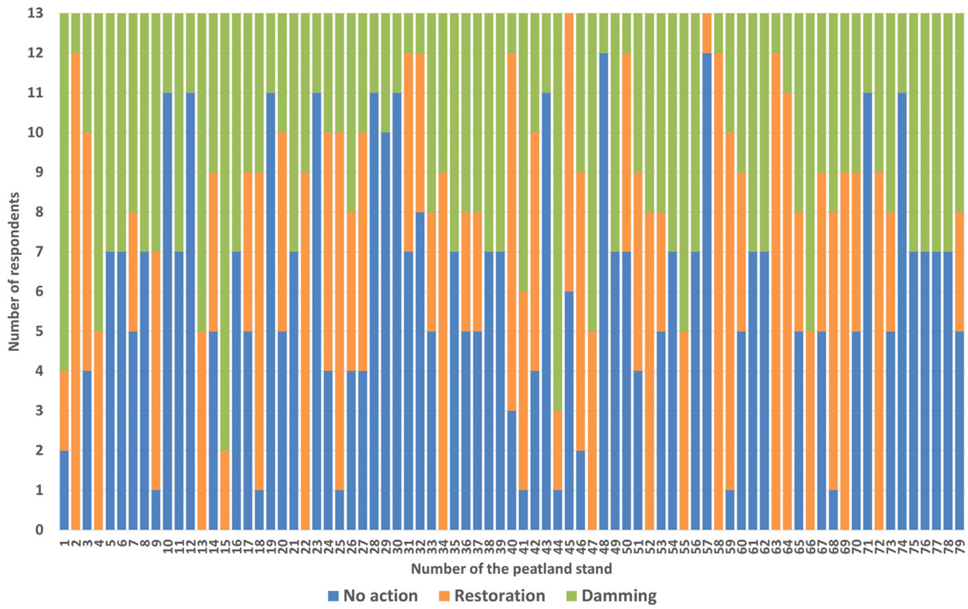


Fig. 5. The number of respondents for whom a particular rewetting option was best on each peatland stand.

A2). In general, biodiversity received the highest weight (median weight 0.36), followed by water quality (0.27), GHG emissions (0.15), recreational use (0.13) and resources (0.06). The high weight assigned to biodiversity was expected, as the target area is dedicated to nature conservation. The small weight for GHG emissions can largely be explained by the fact that many participants considered the significance of GHG emissions resulting from the rewetting options to be negligible compared to the total emissions of the City of Tampere.

The desirability of the rewetting options crucially depended on the type of peatland stand and the weight of the biodiversity criterion. “Restoration” was the best option in terms of biodiversity, but the worst in terms of GHG emissions and nutrient loading. Both the benefits and disadvantages of “Damming” were smaller than those of “Restoration”. The “No action” option was particularly suitable for peatland stands with a high recreational pressure. Fig. 5 illustrates for each peatland stand how many times each rewetting option was ranked best among the participants. Fig. 5 also indicates that there was no single peatland stand in which the same rewetting option was ranked best by all participants. However, for 14 stands, at least 11 of 13 participants had the same best option.

Fig. 6 presents the overall values of different rewetting options for each peatland stand compared to the no action option and by using the median criteria weights of participants. The best management option varied quite considerably between peatland stands. For example, for peatland stand 2, the preference order of the options was “Restoration”, “Damming” and “No action”, whereas for peatland stand 29, the order was the opposite. Fig. 6 also indicates that for large peatland areas, the best management option was disputed. For example, peatland stands 17–28 all belong to the same large peatland area (visualised with the same background colour), but the best rewetting option varied considerably among the stands. Often, these stands are linked so that it is not possible to implement different options on adjacent stands. Thus, based on the results of MAVT, no clear recommendations can be made. As the planners of the City of Tampere wanted to analyse the best rewetting option more carefully for each peatland and the reasons for the rank order, we developed an Excel workbook with visualisations for this purpose. The MAVT results can also be used to manually form a portfolio so that first the rewetting options are ordered according to their overall value and then they are added one-by-one in this order to the portfolio until the restriction of 25 hectares is reached (see Phillips and Bana e Costa 2007, Clemen and Smith 2009).

5.2. RPM

Fig. 7 exemplifies the primary way in which we presented RPM results in the workshop. This illustration from the RPM-Decisions software shows the core indices (CIs) of rewetting options (cf. projects) in decreasing order. Rewetting options with a core index of 100% (coloured green) are included in all efficient portfolios (n=67), and are thus clear choices for the portfolio, despite the impreciseness of the preference information. In contrast, the options with a core index of 0% are not included in any efficient portfolios, and their selection cannot therefore be justified based on any weighting of the attributes. The options that are included in some but not all efficient portfolios have a core index between 0% and 100% (coloured yellow).

In the second workshop, the participants had an opportunity to interact with this visualisation in two ways. First, they were shown how the core indices would change if the ranking of the attributes was changed. In particular, the rewetting options were sorted with regard to the updated core indices under the new preference information. Note that such a ranking is ordinal preference information, as it does not imply crisp numbers for the attribute weights but allows for any weights whose magnitudes are consistent with the given ranking (see, e.g., Salo and Punkka 2005). The second way in which the participants interacted with the results was to manually include borderline options in or exclude them from the portfolio. The software then recomputed the core indices based on only those efficient portfolios that contained (or did not contain) the included (or excluded) option.

5.3. YODA

In this study, the peatland stands were classified into three categories: core stands (defined in this study so that they were selected by at least 6 of the 9 participants), borderline stands (selected by 1–5 participants) and exterior stands (selected by none of the participants, Fig. 8). With this classification, we ensured

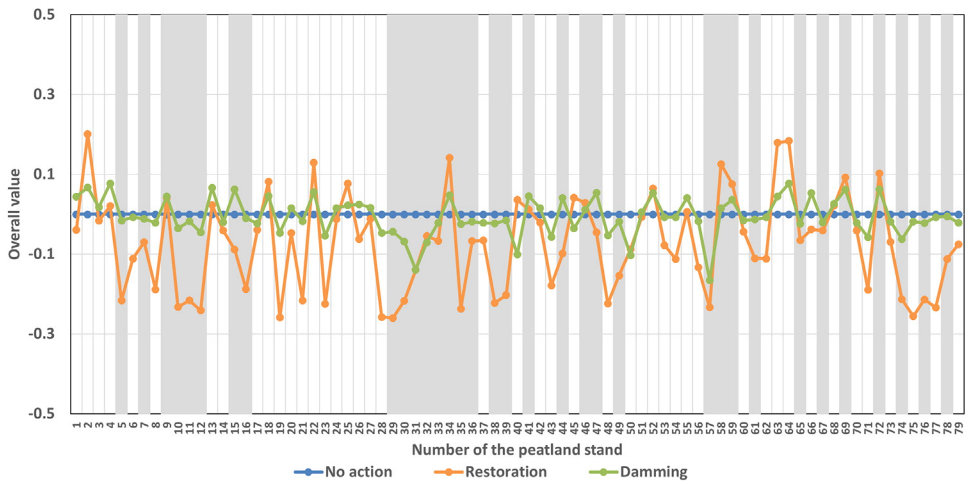


Fig. 6. Overall values of different rewetting options for each peatland stand (calculated with median weights) describing their performance compared to the "No action" option. The white/grey background colour denotes connections between the peatland stands, so that the adjacent peatlands in the chart having the same background colour are also adjacent in nature.

that more than half of the respondents had selected core stands in their portfolios. The discrepancy of the results between the different participants was so great in YODA that the use of RPM's core index (see Section 2.2) would not have produced any viable solutions to the portfolio.

In the case of "Restoration", there were 3 core, 28 borderline and 48 exterior stands. In the case of "Damming", the respective figures were 3, 48 and 28 stands. The same peatland stands were often selected for both "Restoration" and "Damming", whereas 23 stands were not selected for either of the rewetting options. Due to the low number of core projects and the overlap between borderline projects, the superiority between "Restoration" and "Damming" in each stand was assessed separately in the second workshop. After the discussion in the second workshop, the participants delineated that a rewetting option was selected when at least 4 of the 9 participants had selected that instead of at least 6, which was the level set earlier by the YODA experts. After this change, there were 14 stands selected for "Restoration" and 9 stands for "Damming". One stand was selected for both options and 55 stands were not clearly selected for either of the options (1–3 responses) or they were 'Exterior stands'.

Based on the feedback from the respondents, YODA was relatively easy to use after the basic idea was understood. The criteria utilised in the choice varied among the respondents. Biodiversity was the most frequently used criterion, followed by the phosphorus loading and short-term GHG emissions. The selection was mostly based on these three criteria to reach the required 25 hectares. The area of the stand was also used in the selection, since it was considered to influence the biodiversity, GHG emissions and water quality. In fact, stand area was the only criterion that was used in a contradictory way. Most respondents excluded larger stand(s) due to their greater impacts on GHG emissions. However, some respondents preferred larger stands because of their expected higher biodiversity.

5.4. Comparison of the results of the methods

Since the three methods did not convey their results in quantitatively comparable way, we had to develop an approach to make these results comparable. Specifically, we developed criteria for each of the three methods that would classify each stand into one of the categories "No action", "Restoration", "Damming" and "No clear recommendation". In MAVT, if any of the three options received the highest overall value for a specific stand at least with 7 of the 13 participants' weights, then the stand was classified under that option. If none of the options qualified for this condition, then the stand was classified under "No clear recommendation".

Table 3
Number of various rewetting options recommended by the applied decision support methods.

Rewetting option	MAVT	RPM	YODA
"No action"	33	12	55
"Restoration"	16	10	14
"Damming"	9	7	9
"No clear recommendation"	21	50	1

In RPM, a stand was classified under "No action" if both "Restoration" and "Damming" received a core index of 0% (see Fig. 7). In turn, if "Restoration" ("Damming") had a core index exceeding 50%, then the stands was classified under "Restoration" ("Damming"). Recall that the core index measures the share of efficient portfolios that include a specific option, and that for each stand, "Restoration" and "Damming" are mutually exclusive, which implies that the sum of their core indexes cannot exceed 100%. Remaining stands were classified under "No clear recommendation". In YODA, the results were classified into the three categories based on the consensus achieved at the second workshop (see Section 5.3).

The results obtained were quite similar; the methods gave non-contradictory results in terms of the superiority of the rewetting option for 66 peatland stands and contradictory results for 13 stands (Table 3). For 21 of 79 peatland stands, all three methods recommended the same rewetting option. Table 4 presents the differences between the three methods in the distribution of recommended rewetting options. A small surprise was that "No action" was the best option in more than half of the peatland stands for which a clear recommendation was presented in YODA and MAVT. In YODA, there were 55 peatland stands for which the recommendation was "No action", whereas the respective numbers in MAVT and RPM were 33 and 12 peatland stands. On the other hand, in RPM, "No clear recommendation" was presented for 50 peatland stands, whereas in YODA, only one peatland stand belonged to this category. In the second workshop, the results were illustrated by means of maps (Fig. 9).

5.5. Feedback from the participants

The participants' feedback on the methods and their results was gathered via a questionnaire at the end of the second meet-

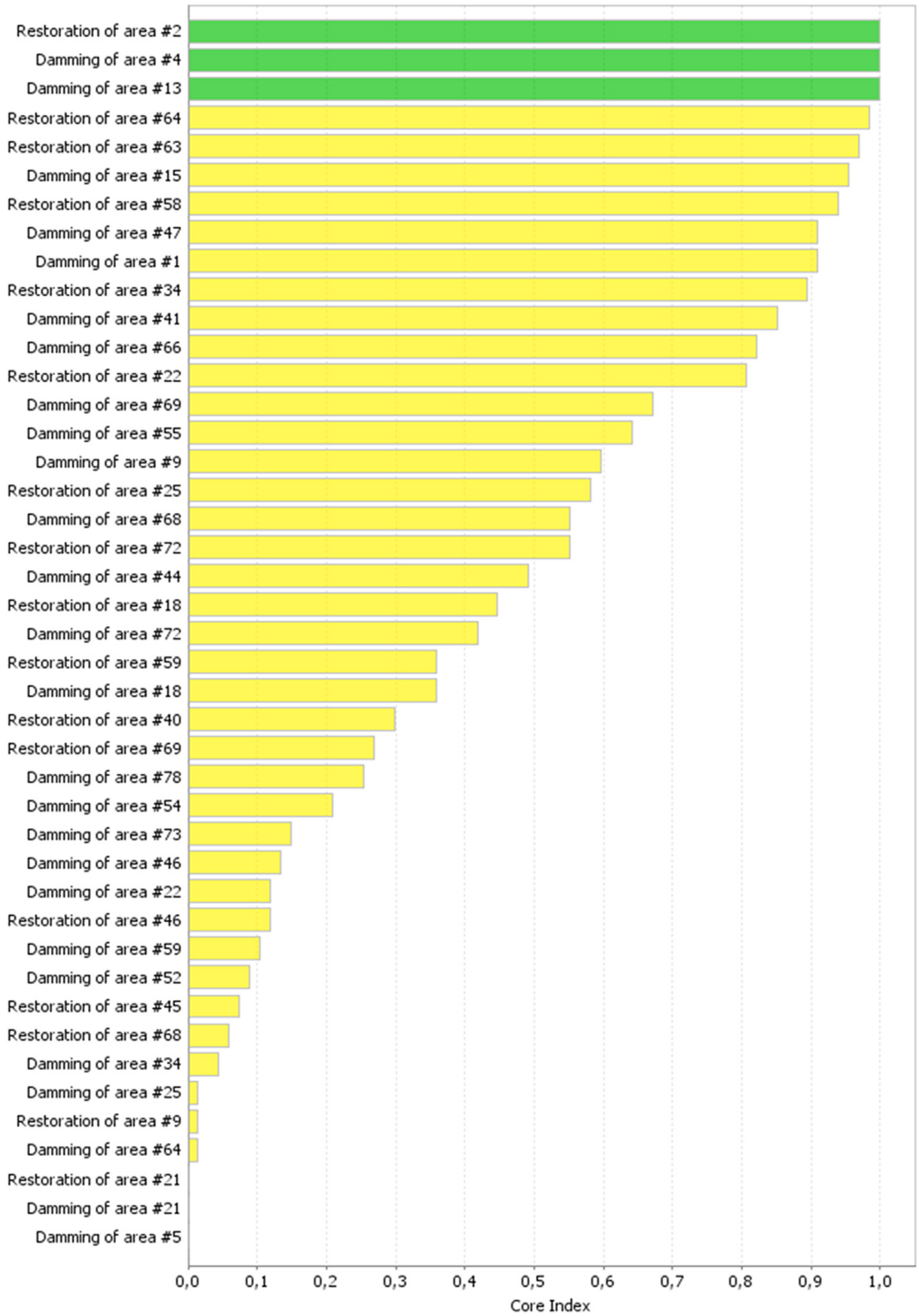
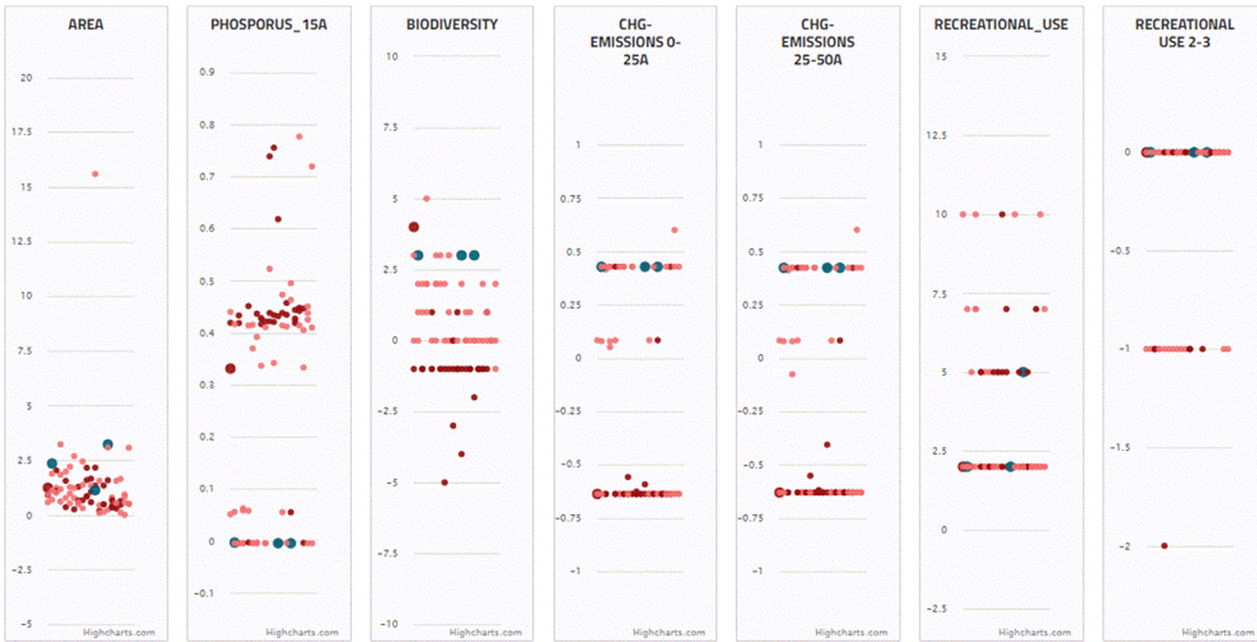


Fig. 7. Core indices (CIs) of the rewetting options based the average weights with ±30% variation. CIs capture the share of efficient portfolios that include each option. Green-coloured options are included in all efficient portfolios (i.e., CI=1). The rewetting options not shown had a zero CI.

ing, and it is presented in Supplementary material A2. The participants considered the methods generally helpful in addressing the rewetting options for drained peatland stands. Most of the respondents felt that the methods were illustrative and that the application of the methods helped them to structure the problem. They would also recommend the use of such methods in future decision-making situations. However, some participants felt that the principles of the methods were difficult to capture and pointed out that a more in-depth introductory session on the methods would have been helpful. This is not surprising, as they had a very limited time to familiarise themselves with the three methods. A few participants also had reservations concerning the reliability of the results due to uncertainties related to the methods. Some also felt that the methods did not provide a good overview of the applicability of different rewetting options for different types of peatland stands.

All three methods received relatively similar feedback. MAVT and YODA appeared to be slightly easier to understand than RPM, perhaps because MAVT was already introduced in the first session and the participants carried out a YODA exercise/tasks on their own laptops before the meeting. MAVT performed slightly better than YODA and RPM for several criteria and received a grade of 8.6, while the other two methods received a grade of 7.6 (on a scale of 4–10, where 4 means very poor and 10 excellent).



Summary (N=9)

RESULTS	AMOUNT	AREA	PHOSPORUS_15A	BIODIVERSITY	CHG-EMISSIONS 0-25A	CHG-EMISSIONS 25-50A	RECREATIONAL_USE	RECREATIONAL USE 2-3
In	3	6.72 ha	-0.01 kg/ha/a	9.00	1.28 CO2-ECV/ha/a	1.27 CO2-ECV/ha/a	9.00	0.00
Strong	0	0.00 ha	0.00 kg/ha/a	0.00	0.00 CO2-ECV/ha/a	0.00 CO2-ECV/ha/a	0.00	0.00
Weak	47	67.03 ha	11.83 kg/ha/a	43.00	-7.39 CO2-ECV/ha/a	-7.42 CO2-ECV/ha/a	161.00	-13.00
Out	29	28.48 ha	12.02 kg/ha/a	-27.00	-15.48 CO2-ECV/ha/a	-15.12 CO2-ECV/ha/a	97.00	-7.00
Max	79	102.23 ha	23.84 kg/ha/a	25.00	-21.59 CO2-ECV/ha/a	-21.27 CO2-ECV/ha/a	267.00	-20.00

Fig. 8. An example of the combined solution for rewetting from YODA based on nine participants' answers depicted through the graphical user interface of YODA (upper part of the figure). The figure also contains a summary table of the results of the stakeholders (lower part of the figure), in which the row "In" shows the number of core stands and the sums of criteria of the core stands, the rows "Strong" and "Weak" present borderline stands ("Strong" stands selected by 5 participants and "Weak" stands selected by 1–4 participants) and "Out" shows exterior stands.

Table 4
Comparison of the recommended stand-specific rewetting options provided by the three methods.

Number of peatland stands with no contradictory recommendations (assuming that "No clear recommendation" is not in contradiction to any other suggestion)			66
	All three recommendations are the same		21
		All are "Restoration"	7
		All are "Damming"	2
		All are "No action"	12
	"No clear recommendation" is suggested once and some other suggestions twice		24
		"Restoration" twice	2
		"Damming" twice	1
		"No action" twice	21
	"No clear recommendation" is suggested twice and some other suggestion once		21
		"Restoration" once	3
		"Damming" once	2
		"No action" once	16
Number of peatland stands with contradictory suggestions			**13**
	All the recommendations are either "Restoration", "Damming" or "No clear recommendation"		7
		"Restoration" twice and "Damming" once	2
		"Damming" twice and "Restoration" once	4
		"Restoration" once, "Damming" once and "No clear recommendation" once	1
	Recommendations include both "No action" and either "Restoration" or "Damming"		6
		"Restoration" twice and "No action" once	2
		"Restoration" once, "No action" once and "No clear recommendation" once	3
		"Damming" once, "No action" once and "No clear recommendation" once	1

Fig. 9. The recommended rewetting options for each peatland stand according to the three decision support methods.

According to the small-group discussion feedback, the rewetting options that were recommended by all methods for certain peatland stands resonated quite well with the participants' initial ideas of good rewetting options for those areas. For example, the City of Tampere had already built dams in three stands in which the methods recommended dams.

However, the participants pointed out that the analysis did not capture some relevant spatial aspects of the decision problem. For example, from a biodiversity perspective, in some cases it might be better to restore a large, unified area consisting of several adjacent stands rather than several smaller fragmented stands, even if the separate stands had a very high biodiversity value as such. With hindsight, it would have been helpful to engage some of the practitioners early on to bring practice-based knowledge to the impact assessment stage.

One question that the participants found challenging in the MAVT/RPM questionnaire was the relative significance of greenhouse gas emissions from the restoration activities compared to the other emission sources of the City Tampere. The environmental sector practitioners placed considerable emphasis on greenhouse gases in general, but they also felt that there are plenty of opportunities to reduce emissions, for example, in traffic or housing, while restoring some of the peatland sites is a unique opportunity to protect biodiversity. Some participants felt that they would have needed more support from the decision analysts in reflecting their preferences.

The small-group discussion also revealed that while the maps indicating the desirability of different rewetting options were well received and stimulated much discussion, some participants were slightly sceptical about the practical value of the methods. As one person pointed out, *"Whatever the computer model says, I am not sure whether it would work in practice ..."*. The uncertainties were linked to the observation that more time would have been needed to introduce the methods and the impact assessment results to the participants. On the other hand, the potential of the methods was also appreciated, as captured by the following comment: *"The models are able to do a huge job, much bigger than a single officer ever could"*. The fact that the different methods gave relatively similar results increased the participants' confidence in the analysis.

6. Discussion

To our knowledge, this was the first study comparing three different multi-criteria decision support methods in a real-life portfolio decision situation. In the following, we discuss the major differences between the methods, identify their strengths and weaknesses and describe how each method was adapted to the decision situation in hand. Finally, we analyse their potential in participatory portfolio decision making, either alone or in conjunction with each other method.

6.1. The reasons for similarities and differences in the results of the methods

The three methods had many similarities in their recommendations regarding the best rewetting options for different peatland stands. In principle, the similarities in the results between the different methods could be due to (i) the characteristics of the alternatives (e.g., some alternatives are good in all/most criteria), (ii) the modelling procedure (e.g., interaction with the participants) and (iii) the structural similarities among the methods.

In our case, the characteristics of the alternatives do not explain the similarity of the results, since the ranking of rewetting options was generally opposite with regard to two criteria receiving the highest weight in MAVT/RPM. That is, the rewetting option that was good in terms of biodiversity was typically poor in terms of water quality (and actually also for most other criteria), and vice versa. Thus, depending on the weighting of the criteria, each option could be either the best or worst one in each peatland stand.

The similarity of the results for MAVT and RPM can be explained by the similarity of the basic principles of the methods, as RPM is based on MAVT (see Section 2.2) and they both used the same criteria weights. However, YODA differed fundamentally from them as a non-aggregated and non-compensatory method (Kurttila et al. 2020) and also produced results that deviated from those of MAVT and RPM. The theoretical background of YODA at the individual user level resembles multi-criteria approval voting methods (e.g., Fraser and Hauge 1998), because it utilises the principle of criteria-level approval/disapproval of decision alternatives.

In YODA, criteria weights are not assigned explicitly, but each criterion is in principle equivalent when thresholds are set for them (Kurttila et al., 2020). However, the user can implicitly consider the importance of the criteria in two ways: (a) by only defining acceptance thresholds for the most important criteria, or (b) by more strictly defining the criterion-level threshold range for the most important criteria. Of these, we could especially observe the first behaviour, as almost all the participants only set acceptance thresholds for two or three criteria, mostly biodiversity and GHG emissions. By setting thresholds for these, a user could readily obtain a solution where the area criterion of 25 hectares was achieved and no additional criteria were therefore needed.

The additive value function used in the MAVT and RPM methods represents a compensatory preference model. Therefore, in MAVT and RPM, an option performing poorly with respect to one criterion can still, due to the compensatory nature of the method, be recommended if it performs well with the other criteria. This could also be noticed in our analysis. For example, in MAVT, 11 respondents assigned the highest weight to biodiversity, and in terms of this criterion, “Restoration” would be the best option for all 79 peatland stands. However, these 11 respondents selected “Restoration” as the best overall option in only 32% of cases (i.e., in 281 of 869 cases [11 different weightings * 79 peatland stands]). Thus, in the majority of cases, “No action” or “Damming” was ranked as the best option, even though these options did not perform well in terms of biodiversity. However, these options performed better than “Restoration” with respect to most of the other criteria, which compensated for their poor performance in biodiversity. Although YODA itself does not have a compensation mechanism, the users can manually include or exclude individual stands to compensate their good or poor performance in terms of some criteria. For example, an option that is close to the acceptance thresholds can be manually included or excluded from the portfolio, depending on how good it is in terms of the other criteria. In our case, three participants utilised this opportunity.

6.2. The strengths and weaknesses of the methods in the case

6.2.1. MAVT

The benefits of MAVT in multi-stakeholder processes (e.g., Marttunen et al. 2015, Ferretti 2020), were also observed in this case. According to the participants’ feedback, the structured process was helpful in clarifying the options and evaluation criteria, as well as the impacts of the options under each criterion. The participants also felt that the facilitated group discussions on the impacts of peatland restoration options supported learning and reflection on their initially held ideas and preferences (see also Munda 2004). The positive rating of the method in the feedback questionnaire aligns with the previous findings that MAVT is a relatively easy and intuitive method that is well suited to participatory decision analysis situations (e.g., Marttunen et al. 2015).

Besides the Excel tool developed for MAVT, we also considered using existing MCDA software for the analysis (see evaluation of the software in Mustajoki and Marttunen 2017). However, none of these programs would have been able to perform the visualisations as well as the Excel tool, as they focus on a single problem, whereas our case had 79 different decision problems (i.e., one for each peatland stand) whose results had to be presented visually in an integrated form. A bar chart that illustrated the strengths and weaknesses of alternatives for a single peatland stand was considered illustrative by the participants (Supplementary material A1.1). The advantage of the simple Excel tool was also that it could be passed on to the city authorities, who could carry out further analyses on their own.

MAVT was applied ‘manually’ to form the portfolio by selecting those peatland stands/rewetting options that provided the highest values, considering both the costs and benefits of each option, until the 25 hectares constraint was achieved. In this respect, MAVT is very flexible, as besides the proposed portfolio, it also provided a ranking order of peatland stands to be rewetted. This makes it easy to adapt the result even to a case in which it is only possible to rewet a few peatland stands at a time, and where the stands to be rewetted next are decided one-by-one over time. One should, however, note that in cases with more constraints, this heuristic approach may not generally yield an efficient portfolio (Phillips and Bana e Costa, 2007).

In MAVT, one challenge is to communicate to the participants that they are expected to consider the range of variation under each criterion instead of the ‘general’ importance of the criteria (Fischer, 1995). To mitigate the range effect (Fischer, 1995), we drew the participants’ attention to the range of impact variation for each criterion. This was further illustrated by presenting a diagram in which the horizontal axis described the general importance of the criterion and the vertical axis the impact range of the alternative, and by emphasising that both dimensions should be considered in weight elicitation (see Marttunen et al. 2019). It appears that the participants captured the idea of impact range relatively well. For example, they regarded greenhouse gas emissions as a very important criterion in general, but in this case, they assigned the criterion ‘climate’ a relatively low value because they maintained that the overall impacts of rewetting and damming of small areas of peatland on GHG is relatively small, while the local biodiversity impacts of restoration of well-selected sites can be considerable. However, some participants indicated that they struggled with putting the GHG impacts into perspective and would have needed more information, for example, on the total GHG emissions of the City of Tampere. The challenge here is to provide adequate information but to avoid an unintentional framing effect (Tversky and Kahneman, 1981). One option is to ask the participants to provide a jointly agreed point of reference for the impacts.

In this case, we paid special attention to the visualisation of the results in MAVT. We developed an approach to the Excel tool in which the results of the individual stakeholder representatives were illustrated so that the negative effects appeared in the bars below the x-axis and the positive effects above it (see Supplementary material 1.1, Fig. 5). Typically, in MCDA, the bars are shown as slices above the x-axis, making it difficult to discern which are negative and which are positive effects. An important choice in the application of MAVT is whether the individual criteria weights provided by participants are aggregated or not (e.g., Belton and Pictet 1997). Based on our previous experience, we presented the results as transparently as possible so that the differences between individuals would become clear (e.g., Fig. 5). The way in which the comparison of “goodness” between alternatives in individual peatland stands was realised received positive feedback, as it easily enabled an overview of the pros and cons of each option. Besides, it was also helpful to analyse the effect of different weight profiles on the ranking order of the alternatives, which many stakeholders were interested in.

6.2.2. RPM

RPM made it possible to determine the priority of peatland stands within constraints (the area to be restored). Two-dimensional diagrams and core-index graphs were regarded as illustrative by some participants, while others found them too complicated and difficult to understand. One of the strengths of RPM is its ability to easily conduct what-if analyses. For example, how does the composition of an efficient portfolio change if different criteria weights are used? In RPM, it is possible to calculate efficient portfolios over different ranges of criteria weights, and in this way identify the best options without precise preference information. As described earlier, these features were utilized both in the "back-office" computations carried-out before the second workshop as well as in the workshop to produce analyses based on preferences statements given by the workshop participants. On the other hand, from the participants' perspective, RPM was cognitively the most demanding method and difficult to grasp without proper familiarisation.

RPM is specifically designed for identifying efficient portfolios under multiple criteria and constraints. Hence, the "Damming" and "Restoration" options for each stand could be readily modelled as mutually exclusive projects, of which at most one can be included in the portfolio. Although RPM utilises the same preference model as MAVT, it adds two layers of additional complexity, namely the consideration of portfolios of actions instead of ranking of actions and the incorporation of incomplete preference information. In our case, RPM results remained unclear to some participants due to the limited time available to present the method and its solution concepts. Thus, in hindsight, it might have been appropriate to also utilise complete preference information (i.e., point-estimate criterion weights) in the RPM model, as this would have made it possible to more precisely assess the benefits of modelling the decision as an explicit portfolio problem.

Determining weights can often be an important and useful step for participants' learning, but it also involves challenges (Marttunen et al., 2018). RPM is a versatile method that can capture any system of linear portfolio constraints, as well as incomplete (preference) information on several problem parameters. Specifically, rather than producing decision recommendations based on the unrealistic assumption that the importance of criteria is precisely captured by point-estimate weights (cf. complete preference information), RPM can utilize, for example, an interval of feasible weights, and identify which action-specific decision recommendations are not contingent on the exact weights and which recommendations change when different weights from these intervals are used. However, the application of RPM requires more expertise from the decision analyst, for instance on mathematical optimisation, compared to standard MAVT.

The choices made in the case were not able to address all the features that are relevant to the final decision making. The peatland stands were examined as separate units in our work. The analysis would have been more realistic if the impacts of the actions on neighbouring hydrologically interconnected peatland stands had also been taken into account. In RPM analysis, it would have been possible to take these types of dependencies into account by explicitly including the synergistic or antagonistic effects between the actions. However, it was not possible to utilize these features in this application: While extending the model to include such interdependencies is relatively straightforward from a technical perspective, estimating the numerical values for the parameters capturing the interaction effects would have required additional workshops to collect expert judgements. Moreover, the current PDA literature does not offer standard processes and methods widely tested in real-life applications for estimating the interaction effects (Liesiö et al., 2021). Indeed, addressing this gap in the PDA literature is an important avenue for future research. In portfolio analysis, one challenge is to take into account effects that are not directly additive (Lahtinen et al., 2017). For example, GHG emissions from different options can be added together, but it was difficult to take biodiversity into account due to the lack of information on the specific impacts of rewetting on different species and the sizes of their populations, as well as preferences over these. For example, would it be better to have as many different species as possible in the area, even if their populations may severely struggle for existence, or fewer species with very healthy populations?

6.2.3. YODA

A fundamental design principle of YODA has been its simplicity, enabling its independent use by stakeholders without analyst support (Hiltunen et al. 2009). In YODA, participating stakeholders have full control of evaluation, but the owners of the decision process can guide the evaluations through, for instance, setting portfolio level goals or constraints or preselection of the projects (Kurttila et al., 2020). Earlier experiences suggest that it is the simplicity of the method that may enhance the legitimacy of the whole planning process and the acceptability of the results (Kurttila et al., 2020). This is of particular importance in cases that are more controversial than our case. On the other hand, the use of a decision analysis method without proper facilitation can increase the possibility of biases (Montibeller and von Winterfeldt, 2015).

In contrast to MAVT and RPM, YODA does not allow the specification of criteria weights but uses acceptance thresholds to capture preferences between options. Almost all participants only set acceptance thresholds for a few criteria, mostly biodiversity and GHG emissions. By setting thresholds for these criteria, a user could readily obtain a solution where the area criterion of 25 hectares was achieved and no additional criteria to limit the cumulative area of selected peatland stands were therefore needed. The selection of criteria for which the thresholds were set may also indirectly indicate the importance of the criteria. Biodiversity received the highest weight in MAVT, and GHG emissions was the third most important criterion after water quality. In MAVT, only four participants assigned zero weight to one criterion, which was either recreational use or resources.

In our case, one advantage of YODA was that it illustrated the trade-offs between GHG emissions and biodiversity, and in a concrete way made it visible that it is not possible to achieve both objectives at the same time. For example, by narrowing the acceptance thresholds of biodiversity, it was possible to immediately notice that the best options with regards to GHG emissions were eliminated from the portfolio. However, similarly to RPM and MAVT, YODA is also prone to bias related to how to perceive the significance of the impacts between the criteria. It should be noted that in YODA, participants did not know which symbol in the display described a specific peatland stand, as they were numbered in the case. Since YODA is designed for cases with only two alternatives, two separate assignments (one for "Damming" and one for "Restoration") were needed. The criteria considered important by the participants were prioritised in defining the acceptance thresholds; hence, the 'worst' stands were cut out first. This led to many participants not using some criteria at all. A challenge in the visual selection was that several peatland stands had exactly the same performance scores (for example, a similar area and soil type led to identical GHG emissions and loading per hectare). As a result, even the slightest change in acceptance thresholds could significantly affect the number and total area of peatland stands included in the portfolio. However, with YODA, it was possible to observe stands one by one and choose one or more stands independently/regardless of the threshold levels.

In YODA, "Damming" and "Restoration" options were analysed in two phases. First, each participant evaluated "Damming" and then "Restoration", and the analyst combined the results of the two analyses with all participants. This approach was somewhat clumsy, and the possibility of simultaneously dealing with two types of options is therefore under consideration for future developments of the software.

GIS-MCDA is a widely and increasingly used method to inform land use planning (e.g., Demesouka et al. 2014, Sward et al. 2021). Presenting the results of each method on a map helped the participants to better understand the results and to discuss their rationality (for example, if there were mutually exclusive suggestions for adjacent interconnected peatland stands). As in the previous YODA case (Kurttila et al., 2020), the participants in this case also proposed the inclusion of an interactive map interface in YODA. While such a representation is undeniably illustrative, there are examples indicating that MCDA-GIS applications can enhance the NIMBY effect ('not in my back yard', denoting the opposition by residents to proposed developments in their local area; see e.g., Kurttila et al. 2020, Sward et al. 2021) if thresholds are chosen to exclude sites that are undesirable to the participant. In this case, it might not be possible to identify the best solutions for the whole, which is one of the key benefits of multi-criteria analysis.

6.3. Ways to combine the methods

One of the strengths of multimethodology is that the selected methods can complement each other so that one method compensates for the weaknesses of another method (Howick and Ackermann 2011, Marttunen et al. 2017). Next, we discuss how different method combinations could have worked in our case, taking into account the synergies between the methods, the resources and expertise required for their application, as well as the cognitive burden and behavioural considerations of the participants. The combinations considered here are MAVT and RPM, YODA and RPM, and MAVT and YODA.

MAVT and RPM: MAVT is a method that complements RPM very well. Despite the similar theoretical foundations, the starting points of the methods are slightly different. For example, in our case, RPM could be considered as a strategic tool for giving an overview of the peatland stands to be rewetted in the long term, whereas MAVT could be seen to be a tactical tool for deciding which stands to rewet next. In addition, the complementary use is rather easy, as the implementation of RPM requires the implementation of all stages of MAVT. That is, if MAVT has already been applied, the additional amount of work required by RPM is not large. However, the use of RPM requires more in-depth OR expertise from the analyst(s), as it involves formulating the portfolio decision setting as an optimisation problem. In simple portfolio problems, MAVT alone can be a useful tool, but the added value generated by RPM increases along with the complexity of the portfolio problem. If there is more than one portfolio constraint (e.g., the maximum number of hectares to be restored in each catchment area in our case), then the use of MAVT-based value-to-cost heuristics to prioritise options becomes more laborious and can lead to an inefficient portfolio. In this case, the benefits of using PDA tools, such as RPM, that explicitly account for all relevant constraints are obvious. From the stakeholders' perspective, applying the methods together is also justified, because MAVT helps to understand alternatives and their impacts, as well as the significance of impacts. It also produces illustrative results that help to understand why some alternatives are chosen for an effective portfolio and others are not.

RPM and YODA: RPM and YODA can be applied sequentially so that RPM is first used to identify portfolios, which are then screened using YODA. This would allow the decision maker to set threshold constraints on the portfolios rather than individual options. By doing so, it is possible to avoid YODA's greatest weakness of not being able to identify efficient portfolios. YODA is also a non-additive and non-compensatory method, which can provide another complementary viewpoint for additive and compensatory RPM. Suggestions for future research on YODA include developing it so that it also allows the setting of thresholds for portfolios along with the individual option, which would widen its application possibilities.

MAVT and YODA: The joint use of YODA and MAVT can be useful if there are many options and there is a need to eliminate some of them before applying MAVT. Both methods make use of information on the effects of the alternatives, so the additional work involved in applying YODA may not be large if the participants are already familiar with the method. However, in YODA, care must be taken to avoid the elimination of alternatives that are slightly worse in one criterion but as good as or better than other alternatives in other criteria. In our case, it can be said that MAVT and YODA were applied in a complementary way, as there was an understanding of the criteria and their importance before applying YODA, although it was not possible to include all criteria in YODA.

6.4. Challenges in the parallel use of multiple methods

We identified several challenges in the parallel use of three decision support methods. Next, we summarise our experiences and make suggestions on how to overcome or alleviate these challenges.

First, using several methods requires additional resources and versatile expertise (e.g., Kotiadis and Mingers 2006, Franco and Montibeller 2010, Franco and Lord 2011). We were able to implement three methods, involve stakeholders and produce practically helpful results in a surprisingly short time (1.5 months in total and two 3 h workshops). However, the prerequisite for this was that the use of time and working methods had been carefully thought out in advance and that the stakeholder group was relatively small, comprising 13 people. Retrospectively, the analysis would have benefited greatly if there had been more time to present the methods and discuss the results. In some of our earlier projects, the MCDA process has lasted one or two years, consisting of several stakeholder meetings and personal interviews, thus providing much better opportunities for individual and social learning among the participants (e.g., Marttunen et al. 2015, see also Bell et al. 2003).

Second, the complementary and comparative application of several decision support methods has been effective with experts (Winkler and Clemen, 2004), but it can be challenging with stakeholders. For example, if the results provided by different methods are not in line with each other, the stakeholders might find the results confusing and even unreliable. Among experts, differences in the outcomes can trigger a constructive discussion on the underlying reasons, but stakeholders are likely to appreciate relatively straightforward results. Fortunately, in our case, there were no major inconsistencies in the results between the methods; instead, reciprocal validation (see Mingers 2002) enhanced confidence in the results. As the outcomes of the methods were presented in different formats, grasping the results was cognitively demanding for the participants. The solution to summarise the results on three different maps, using similar colour coding for the suggested management options, turned out to be very illustrative (see similar findings, e.g., Malczewski 2006).

Third, the redundancy of the methods can decrease participants' engagement in the process and cause frustration. On the other hand, the use of multiple methods can mitigate the risk that the use of models narrows problem framing and suppresses cognitive diversity and organisational conflict. In our case, some phases were common to all three methods (see Fig. 1), which helped us to utilise the same impact data and stakeholder preferences in multiple methods, and consequently to reduce redundancy between the methods.

Finally, perhaps the biggest challenge in the parallel use of methods was to decide how the results of different methods could be comparable in the case where different stakeholders ended up with different portfolios (see 5.4). In the case of MAVT and RPM, the criteria were decided by the researchers, and in YODA, the final decision was made after discussions with stakeholder representatives. The significance of this issue only became clear to us at the time of writing this article, and in retrospect, it would have been important to come up with it even before working with the stakeholders.

6.5. Limitations of the study

In research related to the evaluation of different types of decision analysis methods, there is always a trade-off between realism (strong in real-life case studies) and experimental control (strong in behavioural experiments). Case study and action-research approaches can both be criticised for lacking scientific rigour and providing little basis for generalisation (i.e., producing findings that may be transferable to other settings). In contrast, for example, in experimental student research, students can be divided into parallel groups that receive different guidance or apply different methods or the same methods in a different order, and the validity of the hypotheses is assessed by comparing the results of different groups. However, in real-life cases such as ours, these types of settings are not possible, as stakeholder representatives do not have the resources or time to carry out the same tasks multiple times with different methods, or in the case of each representative carrying out only one task, the number of stakeholders is typically too low to obtain statistically valid results between the groups. However, there are several ways to address these concerns that we tried to follow, including: respondent validation (i.e., participants checking emerging findings and the researcher's interpretation, and providing an opinion as to whether they feel these are accura te) and transparency throughout the research process.

We also recognise that the findings reported here are from a single case, which impairs their generalisation. We have, however, attempted to produce an account that is grounded in a systematic analysis of intervention data, combined with insights from our earlier experience of applying these three decision support methods.

7. Conclusions

This paper analyses the use of three decision support methods in a real-world portfolio decision problem concerning the selection of the most beneficial set of peatland stands and the best rewetting option for each stand within the area constraint. The case was more complicated than a typical portfolio decision situation, as besides selecting which of 79 stands should be rewetted or not, there were also two different options for rewetting (i.e., "Restoration" and "Damming"). We discuss the major challenges in the use of the methods and how we tackled them. We also evaluate, based on our experience and feedback from the participants, how well the selected methods finally fit into this portfolio decision analysis situation.

Our research demonstrates the benefits of multimethod approaches and the complementary ways in which the methods can be used. In particular, MAVT and RPM, which are both multi-criteria methods, worked well together: MAVT illustratively presented the pros and cons of each rewetting option and RPM utilised the same input information to identify projects (in our case, the best rewetting option for each peatland stand) to be included in efficient portfolios within the given constraints. YODA's advantage was that in a concrete way it made it visible that in case of conflicting objectives, it was not possible to achieve both objectives at the same time.

Our experiences suggest that the application of more than one method should be based on careful consideration, as there is a risk that the disadvantages and costs of using more than one method may outweigh the benefits when working with stakeholders. For example, time is often a limited resource, and it is important to decide whether to use it for more in-depth presentations of the principles and results of one method, or for a more superficial description of multiple methods.

One important measure for evaluating the usefulness of methods is how the methods or results are utilised in real decision making. Following the study, the experts of the City of Tampere have applied the study results as follows: When they receive a proposal for rewetting a specific peatland stand, they first check what rewetting options different methods recommend for the stand and whether the recommendations are similar to each other. In addition, they use the Excel tool for analysing in more detail the pros and cons of different options for the particular stand.

The use of multiple decision support methods in portfolio decision problems provides many interesting topics for future research. For example, how might the process be planned if only two decision support methods could be selected instead of three, as in our case? Important aspects in the choice of methods include (i) the need to frame the problem, (ii) the diversity and collaboration among the funding organisations of the actions, (iii) the strength and complexity of interactions among the actions, (iv) the spatial distribution of the actions' consequences and (v) the methodological competencies of the participating stakeholders. In practice, finding answers to these questions requires the gathering of experience of different combinations of methods in different types of decision situations and the development of guidelines to support the choice of methods.

Another topic for further research is the sources of errors and biases, which have received a great deal of attention in the recent decision analysis literature but have not yet received much attention in portfolio decision analysis. Some of the sources of errors and biases are the same as in multi-criteria decision analysis, but there are also PDA-specific biases requiring further research on how to identify and debias them. Spatial multi-criteria decision aiding (SMCDA) is also an important domain to explore the new implications of cognitive and motivational biases (Ferretti, 2020, Ferretti and Geneletti, 2020).

Overall, evaluation of the advantages and disadvantages of applying several decision support methods in a real-world decision situation is a topic for which our project provided some new insights but also raised new questions. There are still many interesting research topics that will hopefully be addressed in future research.

Acknowledgements

This work was supported by the Academy of Finland Project PortRight (Grant No. 323798, 323800, 325430). We would like to thank stakeholders who actively participated in the workshops and brought their expertise and experience to the process.

We are grateful to Jaana Lappeteläinen (City of Tampere) for the very good cooperation during the project.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ejor.2022.09.007.

References

Aalto, M., & Aalto, A. (2018). Opas soiden ennallistamiseen käsityönä. *[Handbook for manual peatland restoration, in Finnish]*. Aallokas Oy. Accessed 26th of September 2022. http://aallokas.fi/data/documents/Opas-soiden-ennallistamiseen-kasityona.pdf.

Al-Shemmeri, T., Al-Kloub, B., & Pearman, A. (1997). Model choice in multicriteria decision aid. *European Journal of Operational Research, 97*(3), 550–560.

Baker, E., Bosetti, V., & Salo, A. (2020). Robust portfolio decision analysis: An application to the energy research and development portfolio problem. *European Journal of Operational Research, 284*(3), 1107–1120.

Bell, M. L., Hobbs, B. F., & Ellis, H. (2003). The use of multi-criteria decision-making methods in the integrated assessment of climate change: Implications for IA practitioners. *Socio-Economic Planning Sciences, 37*(4), 289–316.

Belton, V., & Pictet, J. (1997). A framework for group decision using a MCDA model: Sharing, aggregating or comparing individual information? *Journal of Decision Systems, 6*(3), 283–303.

Belton, V., & Stewart, T. (2010). Problem structuring and multiple criteria decision analysis. *Trends in Multiple Criteria Decision Analysis*, 209–239.

Bicknell, J. E., Collins, M. B., Pickles, R. S., McCann, N. P., Bernard, C. R., Fernandes, D. J., & Smith, R. J. (2017). Designing protected area networks that translate international conservation commitments into national action. *Biological Conservation, 214*, 168–175.

Blichfeldt, B. S., & Andersen, J. R. (2006). Creating a wider audience for action research: Learning from case-study research. *Journal of Research Practice, 2*(1) D2-D2.

Buede, D. M., & Maxwell, D. T. (1995). Rank disagreement: A comparison of multi--criteria methodologies. *Journal of Multi-Criteria Decision Analysis, 4*(1), 1–21.

Cegan, J. C., Filion, A. M., Keisler, J. M., & Linkov, I. (2017). Trends and applications of multi-criteria decision analysis in environmental sciences: literature review. *Environment Systems and Decisions, 37*(2), 123–133.

Cinelli, M., Kadziński, M., Gonzalez, M., & Słowiński, R. (2020). How to support the application of multiple criteria decision analysis? Let us start with a comprehensive taxonomy. *Omega, 96*, 102261.

Clemen, R. T., & Smith, J. E. (2009). On the choice of baselines in multiattribute portfolio analysis: A cautionary note. *Decision Analysis, 6*(4), 256–262.

Cranmer, A., Baker, E., Liesiö, J., & Salo, A. (2018). A portfolio model for siting offshore wind farms with economic and environmental objectives. *European Journal of Operational Research, 267*(1), 304–314.

Crowe, S., Cresswell, K., Robertson, A., Huby, G., Avery, A., & Sheikh, A. (2011). The case study approach. *BMC medical research methodology, 11*(1), 1–9.

De Montis, A., De Toro, P., Droste-Franke, B., Omann, I., & Stagl, S. (2004). Assessing the quality of different MCDA methods. *Alternatives for environmental valuation* (pp. 115–149). Routledge.

Demesouka, O. E., Vavatsikos, A. P., & Anagnostopoulos, K. P. (2014). GIS-based multicriteria municipal solid waste landfill suitability analysis: A review of the methodologies performed and criteria implemented. *Waste Management & Research, 32*(4), 270–296.

Dyer, J. S., & Sarin, R. K. (1979). Measurable multiattribute value functions. *Operations Research, 27*(4), 810–822.

Edwards, W., & Barron, F. H. (1994). SMARTS and SMARTER: Improved simple methods for multiattribute utility measurement. *Organizational Behavior and Human Decision Processes, 60*(3), 306–325.

Ferretti, V., & Geneletti, D. (2020). Does the spatial representation affect criteria weights in environmental decision-making? Insights from a behavioral experiment. *Land Use Policy, 97*, Article 104613.

Ferretti, V. (2020). Insights from an initial exploration of cognitive biases in spatial decisions. *Behavioral Operational Research* (pp. 119–139). Cham: Palgrave Macmillan.

Fischer, G. (1995). Range sensitivities of attribute weights in multiattribute value models. *Organizational Behavior and Human Decision Processes, 62*(3), 252–266.

Fliedner, T., & Liesiö, J. (2016). Adjustable robustness for multi-attribute project portfolio selection. *European Journal of Operational Research, 252*(3), 931–946.

Franco, L. A., & Lord, E. (2011). Understanding multi-methodology: Evaluating the perceived impact of mixing methods for group budgetary decisions. *Omega, 39*, 362–372. https://doi.org/10.1016/j.omega.2010.06.008.

Franco, L. A., & Montibeller, G. (2010). Facilitated modelling in operational research. *European Journal of Operational Research, 205*, 489–500. https://doi.org/10.1016/j.ejor.2009.09.030.

Fraser, N. M., & Hauge, J. W. (1998). Multicriteria approval: Application of approval voting concepts to MCDM Problems. J. *Journal of Multi-Criteria Decision Analysis, 1998*(7), 263–273.

Golabi, K., Kirkwood, C. W., & Sicherman, A. (1981). Selecting a portfolio of soler energy projects using multiattribute preference theory. *Management Science, 27*(2), 174–189.

Gregory, R., Failing, L., Harstone, M., Harstone, M., Long, G., McDaniels, T., & Ohlson, D. (2012). *Structured decision making: A practical guide to environmental management choices*. Chichester, UK: Wiley-Blackwell.

Guarini, M. R., Battisti, F., & Chiovitti, A. (2018). A methodology for the selection of multi-criteria decision analysis methods in real estate and land management processes. *Sustainability, 10*(2), 507.

Guitouni, A., & Martel, J. M. (1998). Tentative guidelines to help choosing an appropriate MCDA method. *European Journal of Operational Research, 109*(2), 501–521.

Hämäläinen, R. P. (2015). Behavioural issues in environmental modelling–the missing perspective. *Environmental Modelling & Software, 73*, 244–253.

Helmstedt, K. J., Shaw, J. D., Bode, M., Terauds, A., Springer, K., Robinson, S. A., & Possingham, H. P. (2016). Prioritizing eradication actions on islands: It's not all or nothing. *Journal of Applied Ecology, 53*(3), 733–741.

Hiltunen, V., Kurttila, M., Leskinen, P., Pasanen, K., & Pykäläinen, J. (2009). Mesta: An internet-based decision-support application for participatory strategic-level natural resources planning. *Forest Policy and Economics, 11*, 1–9.

Hobbs, B. F., & Horn, G. T. (1997). Building public confidence in energy planning: A multimethod MCDM approach to demand-side planning at BC gas. *Energy Policy, 25*(3), 357–375.

Howick, S., & Ackermann, F. (2011). Mixing OR methods in practice: Past, present and future directions. *European Journal of Operational Research, 215*, 503–511. https://doi.org/10.1016/j.ejor.2011.03.013.

Huang, I. B., Keisler, J., & Linkov, I. (2011). Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. *Science of the Total Environment, 409*(19), 3578–3594.

Juutinen, A., Tolvanen, A, Saarimaa, M, Ojanen, P, Sarkkola, S, et al., (2020). Cost-effective land-use options of drained peatlands– integrated biophysical-economic modelling approach. *Ecological Economics, 175*, Article 106704.

Keeney, R. L., Raiffa, H., & Meyer, R. F. (1993). *Decisions with multiple objectives: Preferences and value trade-offs*. Cambridge University press.

Koskinen, M., Tahvanainen, T., Sarkkola, S., Menberu, M. W., Laurén, A, Sallantaus, T., Marttila, H., Ronkanen, A. K., Parviainen, M., Tolvanen, A., Koivusalo, H., & Nieminen, M. (2017). Restoration of nutrient-rich forestry-drained peatlands poses a risk for high exports of dissolved organic carbon, nitrogen, and phosphorus. *Science of the Total Environment, 586*, 858–869.

Kotiadis, K., & Mingers, J. (2006). Combining PSMs with hard OR methods: The philosophical and practical challenges. *Journal of the Operational Research Society, 57*(7), 856–867.

Kurka, T., & Blackwood, D. (2013). Selection of MCA methods to support decision making for renewable energy developments. *Renewable and Sustainable Energy Reviews, 27*, 225–233.

Kurttila, M., Haara, A., Juutinen, A., Karhu, J., Ojanen, P., Pykäläinen, J., & Tolvanen, A. (2020). Applying a multi-criteria project portfolio tool in selecting energy peat production areas. *Sustainability, 12*(5), 1705.

Lahtinen, T. J., Hämäläinen, R. P., & Liesiö, J. (2017). Portfolio decision analysis methods in environmental decision making. *Environmental Modelling & Software, 94*, 73–86.

Laine, A. M., Mehtätalo, L., Tolvanen, A., Frolking, S., & Tuittila, E. S. (2019). Impacts of drainage, restoration and warming on boreal wetland greenhouse gas fluxes. *Science of the Total Environment, 647*, 169–181.

Liesiö, J., & Vilkkumaa, E. (2021). Nonadditive multiattribute utility functions for portfolio decision analysis. *Operations Research, 69*(6), 1886–1908. https://doi.org/10.1287/opre.2020.2046.

Liesiö, J., Mild, P., & Salo, A. (2007). Preference programming for robust portfolio modelling and project selection. *European Journal of Operational Research, 181*(3), 1488–1505.

Liesiö, J., Mild, P., & Salo, A. (2008). Robust portfolio modeling with incomplete cost information and project interdependencies. *European Journal of Operational Research, 190*(3), 679–695.

Liesiö, J., Salo, A., Keisler, J. M., & Morton, A. (2021). Portfolio decision analysis: Recent developments and future prospects. *European Journal of Operational Research, 293*(3), 811–825.

Liesiö, J. (2014). Measurable multiattribute value functions for portfolio decision analysis. *Decision Analysis, 11*(1), 1–20.

Malczewski, J. (2006). GIS-based multicriteria decision analysis: A survey of the literature. *International Journal of Geographical Information Science, 20*(7), 703–726.

Marttunen, M., & Hämäläinen, R. P. (2008). The decision analysis interview approach in the collaborative management of a large regulated water course. *Environmental Management, 42*, 1026–1042.

Marttunen, M., Mustajoki, J., Dufva, M., & Karjalainen, T. P. (2015). How to design and realize participation of stakeholders in MCDA processes? A framework for selecting an appropriate approach. *EURO Journal on Decision Processes, 3*(1-2), 187–214.

Marttunen, M., Lienert, J., & Belton, V. (2017). Structuring problems for multi-criteria decision analysis in practice: A literature review of method combinations. *European Journal of Operational Research, 263*(1), 1–17.

Marttunen, M., Belton, V., & Lienert, J. (2018). Are objectives hierarchy related biases observed in practice? A meta-analysis of environmental and energy applications of multi-criteria decision analysis. *European Journal of Operational Research, 265*(1), 178–194.

Marttunen, M., Weber, C., Åberg, U., & Lienert, J. (2019). Identifying relevant objectives in environmental management decisions: An application to a national monitoring program for river restoration. *Ecological Indicators, 101*, 851–866.

Mingers, J., & Brocklesby, J. (1997). Multimethodology: Towards a framework for mixing methodologies. *Omega, 25*(5), 489–509.

Mingers, J (2002). Multimethodology—mixing and matching methods. In J Rosenhead, & J Mingers (Eds.), *Rational analysis for a problematic world revisited* (pp. 289–309) eds. Chichester: John Wiley and Sons.

Montibeller, G., & Von Winterfeldt, D (2015). Cognitive and motivational biases in decision and risk analysis. *Risk Analysis, 35*(7), 1230–1251.

Montibeller, G., Franco, L. A., Lord, E., & Iglesias, A. (2009). Structuring resource allocation decisions: A framework for building multi-criteria portfolio models with area-grouped options. *European Journal of Operational Research, 199*(3), 846–856. https://doi.org/10.1016/j.ejor.2009.01.054.

Munda, G. (2004). Social multi-criteria evaluation: Methodological foundations and operational consequences. *European Journal of Operational Research, 158*(3), 662–677.

Mustajoki, J., & Marttunen, M. (2017). Comparison of multi-criteria decision analytical software for supporting environmental planning processes. *Environmental Modelling & Software, 93*, 78–91.

Phillips, L. D., & Bana e Costa, C. A. (2007). Transparent prioritisation, budgeting and resource allocation with multi-criteria decision analysis and decision conferencing. *Annals of Operations Research, 154*(1), 51–68.

Phillips, L. D., & Phillips, M. C. (1993). Faciliated work groups: theory and practice. *Journal of the Operational Research Society, 44*(6), 533–549.

Riabacke, M., Danielson, M., & Ekenberg, L. (2012). State-of-the-art prescriptive criteria weight elicitation. *Advances in Decision Sciences, 2012*, 24.

Saarikoski, H., Mustajoki, J., & Marttunen, M. (2013). Participatory multi-criteria assessment as 'opening up' vs. 'closing down' of policy discourses: A case of old–growth forest conflict in Finnish upper Lapland. *Land Use Policy, 32*, 329–336.

Saarimaa, M., Aapala, K., Tuominen, S., Karhu, J., Parkkari, M., & Tolvanen, A. (2019). Predicting hotspots for threatened plant species in boreal peatlands. *Biodiversity and Conservation, 28*, 1173–1204.

Sałabun, W., Wątróbski, J., & Shekhovtsov, A. (2020). Are mcda methods benchmarkable? a comparative study of topsis, vikor, copras, and promethee ii methods. *Symmetry, 12*(9), 1549.

Salo, A., & Punkka, A. (2005). Rank inclusion in criteria hierarchies. *European Journal of Operational Research, 163*(2), 338–356.

Salo, A., Keisler, J., & Morton, A. (2011). An invitation to portfolio decision analysis. *Portfolio decision analysis* (pp. 3–27). New York, NY: Springer.

Sward, J. A., Nilson, R. S., Katkar, V. V., Stedman, R. C., Kay, D. L., Ifft, J. E., & Zhang, K. M. (2021). Integrating social considerations in multicriteria decision analysis for utility-scale solar photovoltaic siting. *Applied Energy, 288*, 116543.

Tolvanen, A., Ollonqvist, P., Perkiö, R., & Uotila, E. (2013). Chapter 12. Ennallistamisen kustannustehokkuus. In K. Aapala, M. Similä, & J. Penttinen (Eds.), *2013. Ojitettujen soiden ennallistamisopas* (pp. 182–185) eds.. Metsähallituksen luonnonsuojelujulkaisuja B [Cost-efficiency of restoration, in Finnish]188.

Tolvanen, A, Tarvainen, O, & Laine, A. (2020a). Soil and water nutrients in stem-only and whole-tree harvest treatments in restored boreal peatlands. *Restoration Ecology, 28*, 1357–1364.

Tolvanen, A., Saarimaa, M., Ahtikoski, A., Kojola, S., Lehtonen, M., Ollila, P. & Sarkkola S. (2020b). Skenaariotarkastelu: Vaihtoehtoskenaariot ls-alueen soilla. Natural Resource Institute Finland. [Alternative scenarios for protected peatlands, In Finnish]. Accecced 26th of September, 2022. http://docplayer.fi/167215789-Skenaariotarkastelu-vaihtoehtoskenaariot-lsalueen.html.

Tolvanen, A., Saarimaa, M., Tuominen, S., & Aapala, K. (2020c). Is 15% restoration sufficient to safeguard the habitats of boreal red-listed mire plant species? *Global Ecology and Conservation, 23*, e01160.

Turkelboom, F., Leone, M., Jacobs, S., Kelemen, E., García-Llorente, M., Baró, F., & Rusch, V. (2018). When we cannot have it all: Ecosystem services trade-offs in the context of spatial planning. *Ecosystem Services, 29*, 566–578.

Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science, 211*(4481), 453–458.

von Winterfeldt, D., & Edwards, W. (1986). *Decision Analysis and Behavioral Research*. Cambridge University Press.

Wątróbski, J., Jankowski, J., Ziemba, P., Karczmarczyk, A., & Zioło, M. (2019). Generalised framework for multi-criteria method selection. *Omega, 86*, 107–124.

Winkler, R. L., & Clemen, R. T. (2004). Multiple experts vs. multiple methods: Combining correlation assessments. *Decision Analysis, 1*(3), 167–176.

Yin, R. K. (1984). *Case study research and applications, design and methods* (4 edition). London: Sage Publications Inc.