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Portfolio value models for capturing project dependencies within disjoint project clusters

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Contents

1 Introduction

Portfolio decision analysis supports decisions in which a subset of projects (i.e. a portfolio) has to be selected from a set of project candidates. Typically, these decisions involve multiple objectives and constraints. The preferences over portfolios are often modeled with an additive-linear multiattribute value function (e.g. Golabi et al. 1981, Ewing Jr. et al. 2006, Liesiö et al. 2007). Use of an additive-linear function requires that addition of a project into the portfolio results in a constant change in the portfolio's overall value independent of which projects the portfolio contains.

This paper develops a model in which the added value from selecting a project depends on which other projects from the same cluster have been selected. These dependencies are captured with symmetric multilinear portfolio value functions developed by Liesiö (2012). The cluster specific values are assumed to be additively independent.

The cluster model is compared with the additive-linear model using real data from a peat extraction application (Ollila 2012). In this application, peat is extracted from swamps for energy production. The extraction causes an environmental risk to water systems. The models minimize the total environmental risk subject to a constraint on the total amount of extracted peat. The swamps are clustered based on which drainage basins they belong to.

This paper is structured as follows. Section 2 presents the peat extraction case with additive-linear and multilinear cluster specific value functions. Section 3 presents the data and compares the results of the different models in a case of incomplete information about criterion weights. Section 4 concludes.

2 Portfolio Model for Peat Extraction

2.1 Additive-linear value model

In the peat extraction application, the total environmental risk to water areas has to be minimized subject to a constraint on the total amount of peat extracted. Ollila (2012) models the environmental risk of peat extraction with an additive-linear function over swamp specific attributes. These attributes are the recreational value and the sensitivity of the water areas near the swamp. The index set of the attributes is denoted by $I = \{1, ..., n\}$, $n = 2$.

Ollila applies the model to a data set of 205 swamps divided into 104 drainage basins, indexed $k \in K = \{1, ..., c\}$, $c = 104$. The number of swamps in a drainage basin varies from 1 to 10. We denote the index set of the swamps in the drainage basin k by J_k. The attributes of the j:th swamp in the cluster k are denoted by $x^k_{jI} = (x^k_{j1}, x^k_{j2})$ which belongs to a set of possible attribute specific performances $X_1 \times X_2$. This set is the same across all drainage basin. The attribute specific values of a swamp are presented with single-attribute value functions $v_1(x^k_{j1}) : X_1 \to [0, 1]$ and $v_2(x^k_{j2}) : X_2 \to [0, 1]$.

A portfolio of swamps is expressed by $x = (x^1, ..., x^k, ..., x^c)$ in which $x^k = (x^k_{1I}, ..., x^k_{|J_k|I})$ consists of the attributes of the $|J_k|$ swamps in the cluster k. In Ollila (2012), the total environmental risk $V(x)$ of a portfolio of swamps x is modeled with a linear-additive value function

$$V(x) = \sum_{k=1}^{c} V^k(x^k), \tag{1}$$

$$V^k(x^k) = \sum_{j=1}^{|J_k|} \sum_{i=1}^{n} w_i v_i(x^k_{ji}), \tag{2}$$

where V^k denotes the environmental risk to the water areas near the drainage basin k. In other words, it is the cluster k specific value function. The weight of criterion i, w_i captures the increase in the total environmental risk from adding a swamp into the portfolio that is at the worst possible level with regard to the attribute i and at the most preferred level with regard to the other attributes. Without loss of generality, the weights are assumed to sum to one.

2.2 Additive-multilinear value function for clusters

The use of linear-additive value function (1) requires that the additional environmental risk from adding a swamp into the portfolio does not depend on which swamps are already included in the portfolio (for more detailed discussion on the assumptions, see, Golabi et al. 1981, Liesiö 2012). However, this assumption does not necessarily hold when peat is extracted from many swamps located in the same drainage basin. Taking peat from additional swamps in the same drainage basin could result in a decreasing (or increasing) environmental risk. For example, consider that extracting peat from a swamp causes the water clearness to change from clear to moderately muddy and extracting peat from two swamps in the same drainage basin causes a change from moderately to very muddy water. If the change in water clearness from clear to moderately muddy is more valuable than the change from moderately muddy to very muddy water, the added environmental risk of the second swamp is greater than the added environmental risk of the first swamp.

Due to the concerns described above, we adjust the model (1) such that the drainage basin specific value function, $V^k(x^k)$, is not an additive-linear function over swamp specific values. We use the additive-multilinear portfolio value functions (Liesiö 2012),

$$V^k(x^k) = \sum_{i=1}^{n} V_i^k(x^k_{J_k i}), \quad \textit{where} \tag{3}$$

$$V_i^k(x^k_{J_k i}) = \sum_{J' \subseteq J_k} w_i(|J'|) \prod_{j \in J'} v_i(x^k_{ji}) \prod_{j \notin J'} (1 - v_i(x^k_{ji})), \tag{4}$$

in which $w_i : \{0, ..., |J_k|\} \to [0, 1]$ is a strictly increasing weighting function. $w_i(s)$ captures the increase in the total environmental risk from adding s swamps into the portfolio that are at the worst possible level with regard to the attribute i and at the most preferred level with regard to the other attributes. In addition to specifying the attribute specific value functions of the swamps v_i, the value function (3) requires specifying the weighting functions w_i for each attribute i. As a special case, when $w_i(s) = s \cdot\ w_i(1)$ for all i, the multi-linear value function (3) corresponds to the additive-linear value function (2).

The attribute specific value functions of a cluster (4) are symmetric multi-linear functions. Their value increases linearly when the attribute specific value of any single swamp is increased and the attribute specific values of other swamps are held constant.

2.3 An optimization model for the portfolio selection

To formulate the portfolio selection as an optimization problem, we introduce binary decision varibles $z = (z^1, ..., z^k, ..., z^c)$, $z^k \in \{0,1\}^{|J_k|}$ such that $z_j^k = 1$ if the j:th project of the cluster k is selected into the overall portfolio and 0 if it is not selected.

The portfolio with the lowest environmental risk to the water areas, restricted by linear constraint on how much peat has to be extracted in total, can be identified with an integer programming model

$$\min_z V(\hat{x}^1(z^1), ..., \hat{x}^k(z^k), ..., \hat{x}^c(z^c)) \text{ s.t. } Az \geq b, \tag{5}$$

where the functions $\hat{x}^k : \{0,1\}^{|J_k|} \to X^k$ map the decision variables z^k to the project specific performances such that $\hat{x}_j^k(z^k) = (x_{j1}^{go}, x_{j2}^{go})$ if $z_j^k = 1$ and $\hat{x}^k(z^k) = (x_{j1}^{no}, x_{j2}^{no})$ if $z_j^k = 0$. The x_{ji}'s with superscripts 'go' and 'no' refer to the performance of the project when it is selected or when it is not selected into the portfolio. The amount of peat in each swamp is coded into the matrix A and the total amount of peat to be extracted is denoted by b.

Liesiö (2012) notes that the function (4) can often be approximated accurately by a piecewice linear function $\tilde{V}_i(\sum_{j=1}^m v_i(x_{ji}))$. More specifically, a linear intrapolation of the weighting function $w_i(d)$ between points $d \in \{0, ..., |J_k|\}$ can be used as the function $\tilde{V}_i$. Using a piecewise linear approximation of the value function, the problem (5) becomes a mixed integer linear programming (MILP) model

$$\min_{z^k, \theta^{ki}, \psi^{ki}} \sum_{k=1}^{c} \sum_{i=1}^{n} \sum_{d=0}^{|J_k|} \theta_d^{ki} \tilde{w}_i(d) \tag{6}$$

$$Az \geq B,$$

$$\sum_{j=1}^{n} z_j^k v_i(x_{ji}^k) = \sum_{d=0}^{|J_k|} \theta_d^{ki} d \;\; \forall i \in I, k \in K \tag{7}$$

$$\sum_{d=0}^{|J_k|} \theta_d^{ki} = 1 \;\; \forall i \in I, k \in K$$

$$\sum_{d=0}^{l_i - 1} \psi_d^{ki} = 1 \;\; \forall i \in I, k \in K$$

$$\theta_0^{ki} \leq \psi_0^{ki} \;\; \forall i \in I, k \in K$$
$$\theta_d^{ki} \leq \psi_{d-1}^{ki} + \psi_d^{ki} \;\; \forall d \in \{1, ..., m^* - 1\}, i \in I, k \in K$$
$$\theta_{m^*}^{ki} \leq \psi_{m^*-1}^{ki} \;\; \forall i \in I, k \in K$$
$$\theta^{ki} \in [0,1]^{|J_k|+1}, \psi^{ki} \in \{0,1\}^{|J_k|} \;\; \forall i \in I, k \in K.$$

The function $\tilde{w}_i : [0, \max\{|J_k| : k \in K\}] \to [0,1]$ in (6) denotes the piecewise linear approximation of the attribute specific symmetric multilinear function. The variable c denotes the number of clusters, n the number of criteria and $m^* = \max\{|J_k| : k \in K\}$ the number of swamps in the largest cluster.

3 A Numerical Example

In this section, the results of the peat extraction case are compared when different cluster specific value functions are employed in a case of incomplete information.

3.1 Data

The attribute specific values of swamps and the amounts of peat that can be extracted from each are presented in Table 2. In our example 51% of the total peat is extracted. We use the additive-multilinear value functions (3) to model the interdependencies within clusters. For demonstration we calculate the results with three different weighting functions that satisfy

$$w_i(d+1) - w_i(d) = r[w_i(d) - w_i(d-1)], d \in \{0, ..., m\} \; \forall i \in I. \tag{8}$$

In all three cases, we use the same weighting functions for both attributes. We calculate the results with $r = 1$, 0.7 and 1.3. These lead to linear, convex and concave weighting functions respectively. A convex weighting function implies that the additional environmental risk from extracting peat from a swamp increases as more swamps are selected from the cluster it belongs to. A concave weighting function implies that the additional environmental risk from extracting peat from a swamp decreases as more swamps are selected from the cluster it belongs to. In Figures 1-3, the dots correspond to the values of the weighting functions for the three cases. In cases $r = 0.7$ and $r = 1.3$, the multilinear function is multiplicative (Liesiö, 2012). The grey area corresponds to the set of points $\{(\sum_{j=1}^m v_i(x_{ji}), V_i(x_{Ji}))|x_{Ji} \in X_{Ji}\}$.

We use the linear intrapolation of the weighting function as an approximation for the symmetric multilinear function $V_i(x_{Ji})$. The approximation is good for the multilinear functions in Figures 1-3. In Figure 1 the absolute difference $|\tilde{w}_i(\sum_{j=1}^{m} v_i(x_{ji})) - V_i(x_{Ji})|$ is 0 at every point because the multilinear function is linear. In Figure 2 the maximum absolute difference is 0.05. In Figure 3 the maximum absolute difference is 0.0354. These maximum errors are small. In the concave case, the weighting function is at the upper limit of the grey area. In the convex case, the weighting function is at the lower limit of the grey area. Therefore, the errors are biased in one direction.

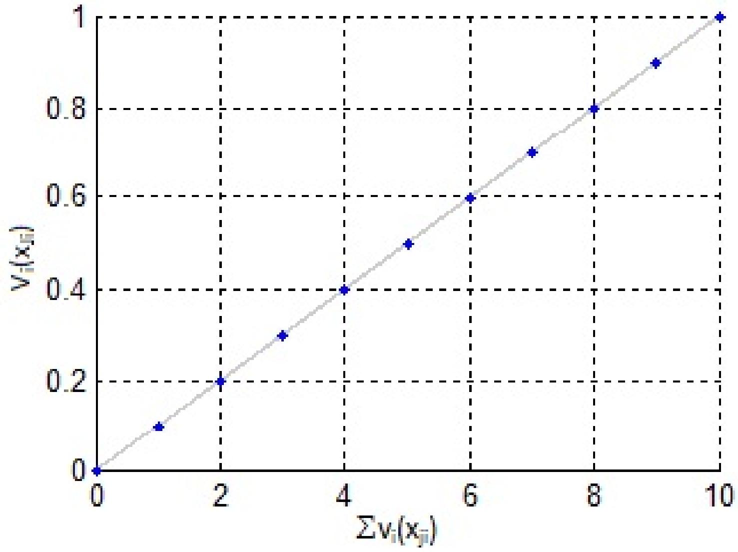


Figure 1: A weighting function determined by the equation (8) with $r = 1$. The grey are correponds to the set of possible values for a multilinear value function scaled to an interval $[0, 1]$.

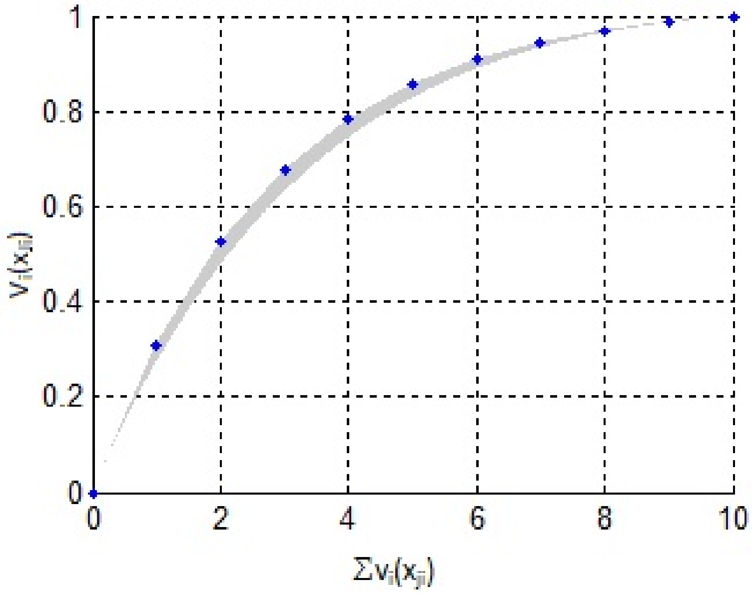


Figure 2: A weighting function determined by the equation (8) with $r = 0.7$. The grey are correponds to the set of possible values for a multilinear value function scaled to an interval $[0, 1]$.

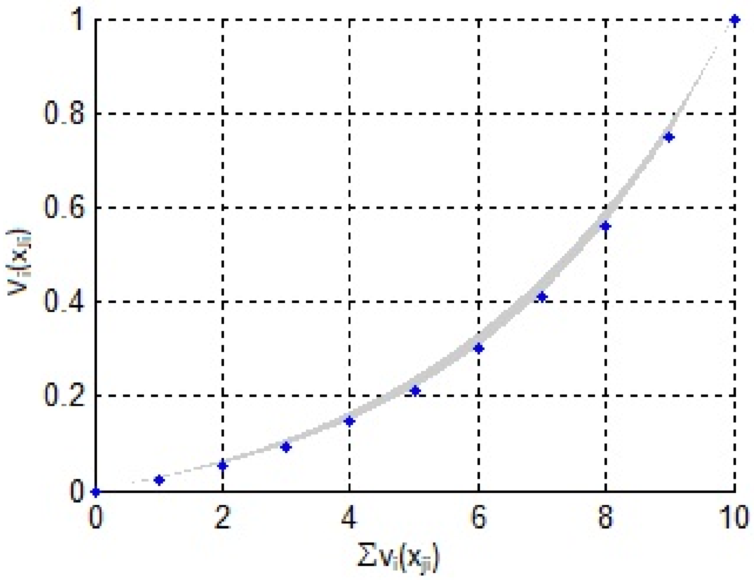


Figure 3: A weighting function determined by the equation (8) with $r = 1.3$. The grey are correponds to the set of possible values for a multilinear value function scaled to an interval $[0, 1]$.

3.2 Results

We calculate the results with incomplete information about the attribute weights. Incomplete information can be used when more precise information on the attribute weights is not available. We assume no information about the weights $w_i(1)$ and calculate the optimal portfolios when $w_1(1)$ goes over a grid of 1000 points distributed uniformly to $[0,1]$ and $w_1(1)+w_2(1)=1$. A portfolio that minimizes the total environmental risk $V(x)$ for some attribute weights is a potentially optimal portfolio. Let $z^*(w)$ denote the optimal solution to (6) with weights $w=(w_1(1),w_2(1))$.

By core index (CI; Liesiö et al. 2007) of a swamp j in cluster k, we refer to the proportion of the calculated potentially optimal portfolios it belongs to when no restrictions to the weights have been given, i.e.,

$$CI_{PO}(k,j)=\frac{|\{z \mid \exists w \geq 0 \text{ s.t. } z=z^*(w) \text{ and } z_j^k=1\}|}{|\{z \mid \exists w \text{ s.t. } z=z^*(w)\}|}, \tag{9}$$

where $|\{.\}|$ refers to the number of elements in the set $\{.\}$. A swamp with $CI=1$ belongs to the optimal portfolio, no matter how the weights are selected. These swamps are referred to as *core swamps*. Swamps with $CI=0$ are referred to as *exterior swamps*, they do not belong to the optimal portfolio with any weights. The swamps with $CI \in]0,1[$ are referred to as *borderline swamps*, they belong to the optimal portfolio with some weights.

In Figures 4 and 5, 205 swamps are presented in descending order with regard to the CI in the linear model. The first column of bars correspond to the linear model, the second column to the concave model and the third column to the convex model. In Figures 5 and 6, the swamps are sorted in descending order with respect to cluster size and every other cluster is highlighted with different color. Inside the clusters, the swamps are arranged in descending order w.r.t. the CI in linear model.

Figure 4: CIs of the swamps, when w_i:s are linear (first column), concave (second column) and convex (third column). The swamps are listed in descending order of CIs in column 1.

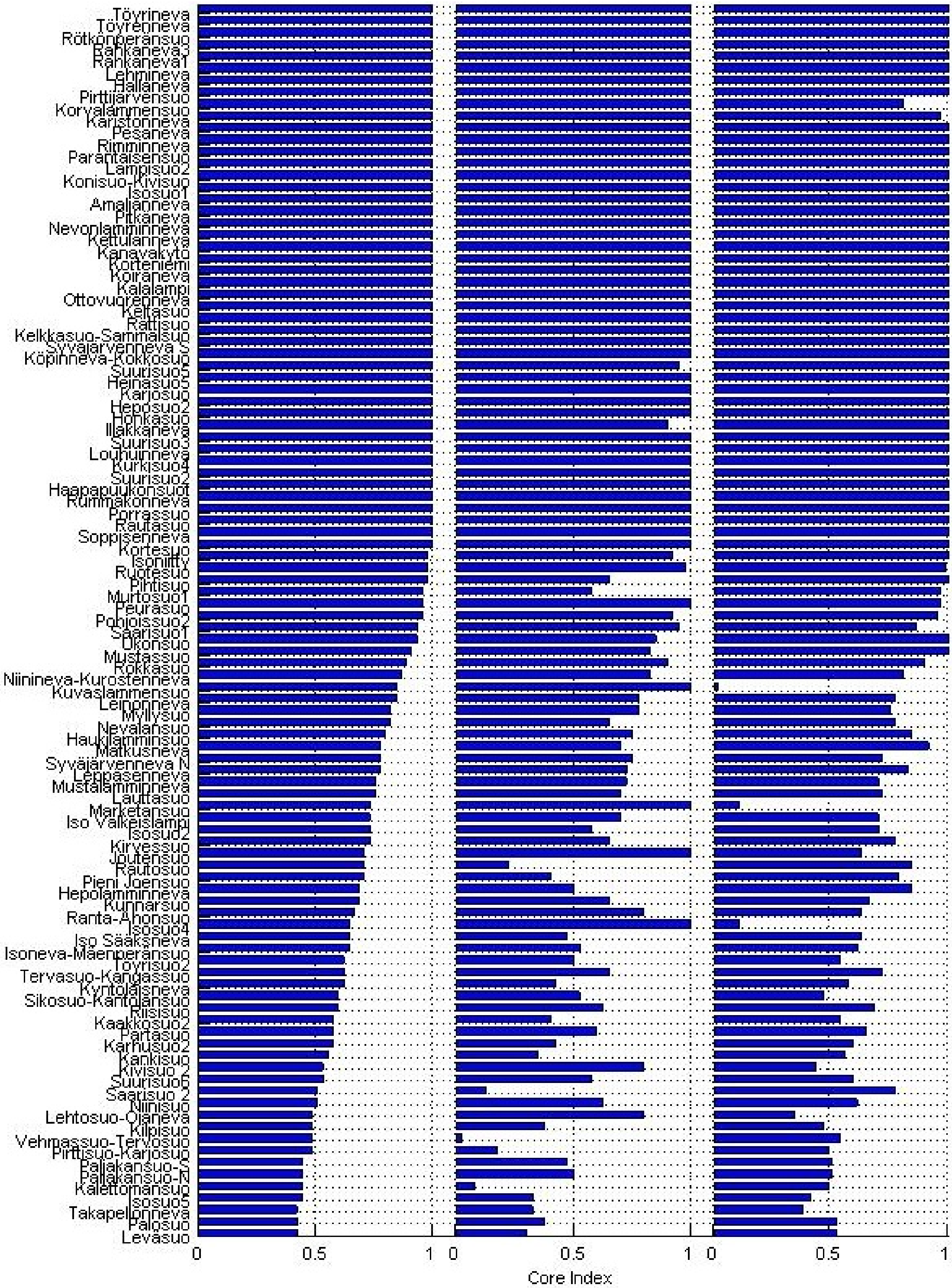


Figure 5: CIs of the swamps, when w_i:s are linear (first column), concave (second column) and convex (third column). The 104 swamps are listed in descending order of CIs in column 1.

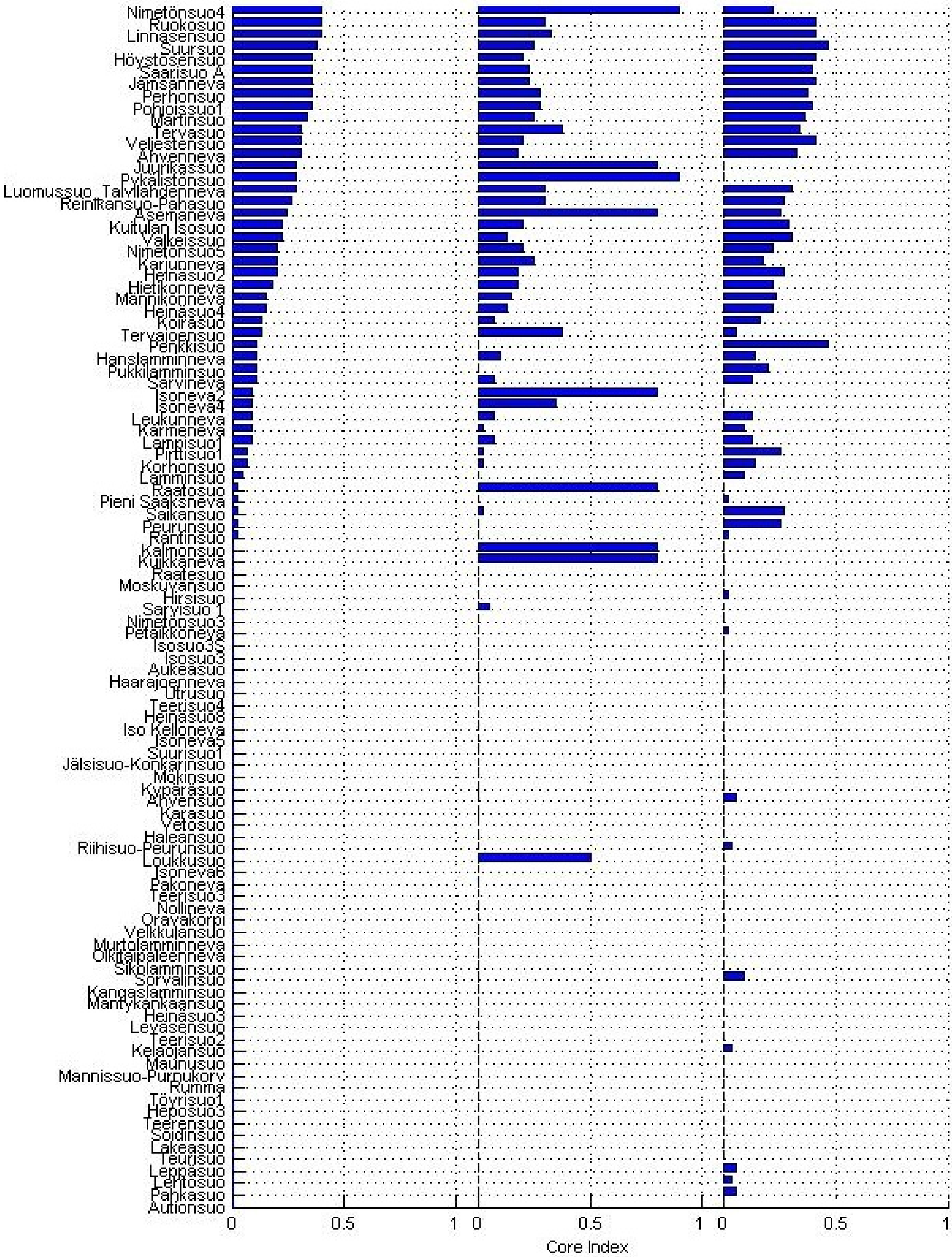


Figure 6: CIs of the swamps, when w_i:s are linear (first column), concave (second column) and convex (third column). The swamps are listed in descending order w.r.t. the cluster size. Every other cluster is coded with different color.

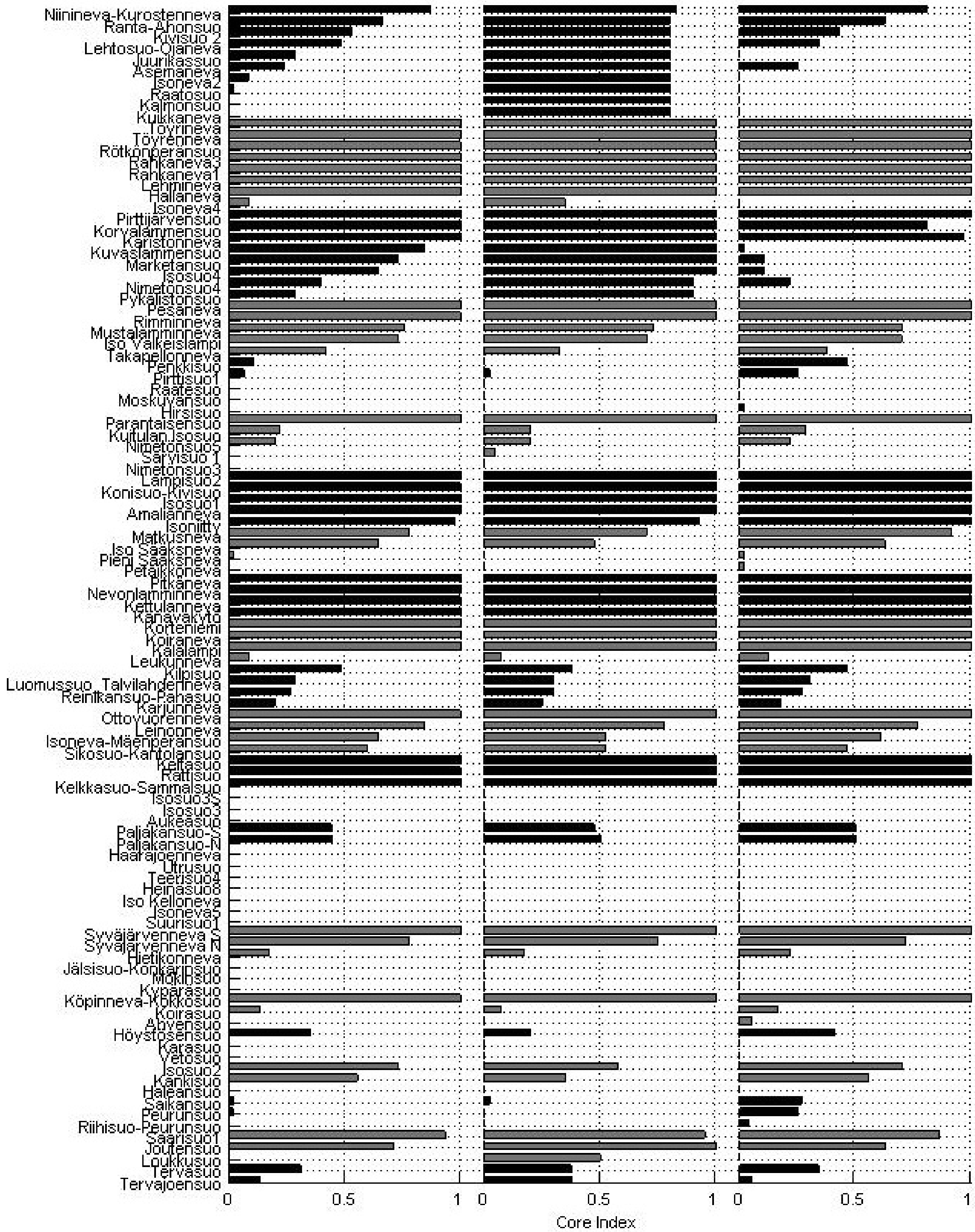
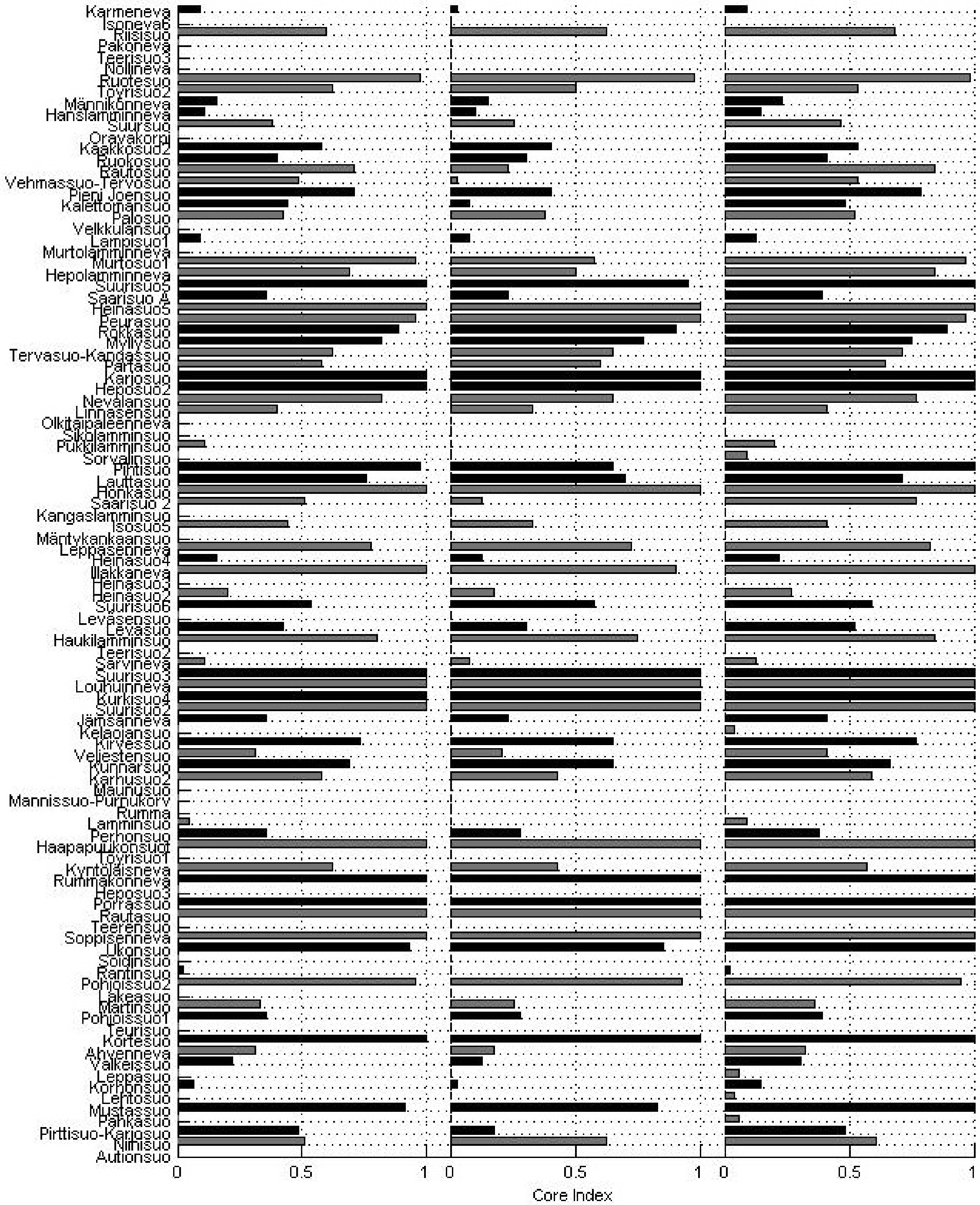


Figure 7: CIs of the swamps, when w_i:s are linear (first column), concave (second column) and convex (third column). The swamps are listed in descending order w.r.t. the cluster size. Every other cluster is coded with different color.



3.3 Discussion

Most of the 46 core swamps of the linear model (Figure 4) are core swamps also in the concave and convex models. Only 4 of them are not core swamps in the concave or the convex model. The difference between CI in the linear model and CI in the other models is larger for the borderline swamps of the linear model. For example, 5 borderline swamps of the linear model are core swamps in the concave model and 3 borderline swamps of the linear model are core swamps in the convex model.

Figure 5 shows that some of the swamps with low CI in the linear model have high CI in the concave model. The swamps with low CI in the linear model also have low CI in the convex model.

Figure 6 shows that the difference between CIs in the different models are the greatest for the swamps in the largest and the third largest clusters. In these clusters the CIs are highest in the concave model and lowest in the convex model. The concave model favors the swamps in large clusters because the additional risk from extracting peat from more swamps is decreasing.

Table 1 highlights swamps whose CI differs substantially between the models. The table shows the swamps' CIs in each of the three models and gives additional information about the cluster the swamp is in. The table is divided into four sections. The swamps in the first section are from small clusters which explains why they have a higher CI in the convex model than in the concave model. In rest of the sections, the swamps have highest CI in the concave model because the swamps belong to a cluster that contains lot of peat.

	Core Index			
Swamp	**Linear**	**Concave**	**Convex**	**Additional information**
Pihtisuo	0.98	0.65	1	In a cluster of two swamps
Murtosuo	0.96	0.58	0.96	In a cluster of two swamps
Rautosuo	0.71	0.23	0.84	In a cluster of two swamps
Saarisuo2	0.51	0.13	0.77	In a cluster of two swamps
Kuvaslammensuo	0.84	1	0.02	In the third largest cluster
Marketansuo	0.73	1	0.11	In the third largest cluster
Isosuo4	0.64	1	0.11	In the third largest cluster
Nimetönsuo4	0.4	0.9	0.21	In the third largest cluster
Pykstönsuo	0.29	0.9	0	In the third largest cluster
Asemaneva	0.24	0.8	0.25	In the largest cluster
Juurikassuo	0.29	0.8	0	In the largest cluster
Isoneva2	0.09	0.8	0	In the largest cluster
Raatosuo	0.02	0.8	0	In the largest cluster
Kuikkaneva	0	0.8	0	In the largest cluster
Kalmonsuo	0	0.8	0	In the largest cluster
Joutsensuo	0.71	1	0.63	2.4 $\times$ average peat
Loukkusuo	0	0.5	0	Same cluster with Joutensuo

Table 1: The CIs for selected swamps for which the core index varies substantially across the different models

4 Conclusions

We modeled the value of a portfolio as a sum of additive-multilinear cluster specific value functions. The model was applied to a real data set from a peat extraction application. We used incomplete information about attribute weights and compared results when the cluster specific value functions were convex, concave and linear.

The core indicies (CIs) differ the most across the three models for projects (swamps) that belong to the largest clusters (drainage basins). The CIs alter only a little for the core projects of the linear model. They are robust to changes in attribute weights and to changes in shape of the value function. The CIs of the borderline projects of the linear model vary the most across the different models. For some projects, the differences between the models are substantial. This suggests that correctly specifying the shapes of the weighting functions can be important.

It would be interesting to study how the results change when the incomplete information is more precise. In this study, no information about attribute weights was assumed. The effect of the distribution of the cluster sizes to the results could also be studied. More thorough testing would help knowing when the linear-additive model is a good approximation and when it can fail.

Clustering the projects into the smallest possible additive units and using the cluster specific non-linear value functions provides an alternative way of modeling the interaction between project values compared to enumeration of interacting projects (for example, Liesiö et al. 2007). The approach is similar to reformulating the evaluation criteria in the case when additivity assumptions over criterion specific values do not hold (see, for example, Ewing et al. 2006). The approach can reduce the elicitation burden compared to specifying all possible interactions separately. It is possible, that the computational burden is lighter as well. However, the interdependencies must have a structure that can be captured with cluster specific value functions. A possible direction of future studies could be more detailed specification of what types of project interactions can be modeled with the clustering approach.

Broadly the models developed in this paper can be applied to contexts where a resource constraint binds the portfolio selection and the values of interdepedent projects can be modeled with cluster specific value functions. Such situations can arise when one decision maker selects a portfolio of projects that serve different goals. The goals can be, for example, utilities of different people or division specific performances. For example, targeting multiple marketing campaigns to same audience can have more effect than targeting the campaigns to different audiences. In that case, a cluster would consist of campaigns targeting the same audience.

Appendix

Table 2: Finnish drainage basin classification codes, attribute specific scores, and peat amounts of the swamps

Name	Drainage basin	Value of the water area	Sensitivity score	Amount of peat
Kangaslamminsuo	14.236	0.557250656	0.344705205	0.695
Isosuo5	14.263	0.347749843	0.122899799	0.305
Keltasuo	14.273	0.079286005	0.114130492	0.36
Rättisuo	14.273	0.074639108	0.143125705	0.38
Kelkkasuo-Sammalsuo	14.273	0.078904199	0.132758339	0.3
Isosuo3S	14.295	0.261473347	0.062492896	0.12
Isosuo3	14.295	0.278944299	0.136227518	0.26
Aukeasuo	14.295	0.263591503	0.312892841	0.61
Mäntykankaansuo	14.296	0.18162039	0.277349741	0.37
Leppäsenneva	14.318	0.020997375	0.495268764	0.97
Heinäsuo4	14.355	0.084481627	0.389525806	0.59
Illakkaneva	14.364	0.095874392	0.152064898	0.32
Heinäsuo3	14.367	0.72472698	0.334119582	0.54
Heinäsuo2	14.372	0.042650919	0.336144696	0.53
Suurisuo6	14.373	0.083333333	0.557634518	1.04
Leväsensuo	14.374	0.244422572	0.416535013	0.57
Leväsuo	14.376	0.096620735	0.256823818	0.48
Haukilamminsuo	14.377	0.050998833	0.3735604	0.74
Paljakansuo-S	14.378	0.01148294	0.279492811	0.49
Paljakansuo-N	14.378	0.01148294	0.29090068	0.51
Haarajoenneva	14.378	0.320866142	0.262128837	0.38
Tervasuo	14.379	0.099409449	1.088397066	1.78
Tervajoensuo	14.379	0.098425197	0.335398035	0.53
Teerisuo2	14.381	0.43011811	0.35195887	0.51
Utrusuo	14.394	0.375649453	0.565920483	0.87
Teerisuo4	14.394	0.588535671	0.163277798	0.25
Heinäsuo8	14.394	0.609162753	0.346088894	0.54
Isoneva6	14.414	0.186816012	0.087615958	0.15
Karmeneva	14.414	0.187800264	0.350463832	0.6
Riisisuo	14.421	0.040124096	0.43584311	0.82
Pakoneva	14.421	0.176181102	0.143164656	0.26
Sarvineva	14.423	0.143866748	0.065263957	0.135
Teerisuo3	14.429	0.102865842	0.122972259	0.21
Nollineva	14.429	0.251968504	0.084189237	0.165
Suurisuo3	14.434	0.111220472	0.138757733	0.31
Iso Kelloneva	14.441	0.083169291	0.055512194	0.105
Isoneva5	14.441	0.260826772	0.145389079	0.275
Suurisuo1	14.441	0.561515748	0.499084781	0.96
Ruotesuo	14.443	0.085137795	0.082760708	0.22
Töyrisuo2	14.443	0.17191601	0.088421814	0.22
Mustalamminneva	14.444	0.094054581	0.067131392	0.165
Iso Valkeislampi	14.444	0.094054581	0.065097107	0.16
Pesaneva	14.444	0.104288499	0.185119898	0.455
Takapellonneva	14.444	0.201888689	0.068824737	0.175
Rimminneva	14.444	0.198646222	0.253513974	0.6
Töyrineva	14.445	0.016916471	0.09806625	0.31
Töyrenneva	14.445	0.013514758	0.174828804	0.56
Rötkönperänsuo	14.445	0.014170926	0.132863952	0.42
Rahkaneva3	14.445	0.012139108	0.154412949	0.47
Rahkaneva1	14.445	0.003937008	0.171463625	0.52
Lehmineva	14.445	0.005051726	0.217626909	0.66
Hallaneva	14.445	0.014107612	0.225840073	0.62
Isoneva4	14.445	0.487040682	0.14191431	0.3
Louhuinneva	14.446	0.100371637	0.157557595	0.34
Syväjärvenneva S	14.447	0.246768085	0.336784574	1.06
Syväjärvenneva N	14.447	0.24856775	0.120194067	0.36
Hietikonneva	14.447	0.24856775	0.01669362	0.05
Kurkisuo4	14.449	0.100885827	0.121620765	0.33
Iso Sääksneva	14.453	0.246049562	0.225628376	0.49
Petäikköneva	14.453	0.247033814	0.059979241	0.12
Pieni Sääksneva	14.453	0.240813648	0.069975781	0.14
Matkusneva	14.453	0.240813648	0.559806249	1.12
Pitkäneva	14.457	0.020655861	0.146923307	0.4
Nevonlamminneva	14.457	0.029784654	0.183654134	0.5
Kettulanneva	14.457	0.029784654	0.106519398	0.29
Kanavakytö	14.457	0.024385658	0.237232505	0.61

Name	Drainage basin	Value of the water area	Sensitivity score	Amount of peat
Suurisuo2	14.463	0.119750656	0.174598019	0.38
Jämsänneva	14.481	0.083497375	0.233870662	0.425
Männikönneva	14.492	0.06690611	0.355514424	0.535
Hanslamminneva	14.492	0.066929134	0.198685877	0.3
Suursuo	14.498	0.076323656	0.250272262	0.455
Oravakorpi	14.498	0.166174541	0.170515168	0.31
Kelaojansuo	14.514	0.231117903	0.14840364	0.3
Kirvessuo	14.522	0.168471129	0.143205411	0.33
Veljestensuo	14.523	0.18093832	0.365794276	0.69
Ruokosuo	14.524	0.338433984	0.18195254	0.41
Kaakkosuo2	14.524	0.340822666	0.232988009	0.525
Kunnarsuo	14.526	0.215300801	0.116513909	0.305
Karhusuo2	14.528	0.209153543	0.139766256	0.325
Maunusuo	14.541	0.344941943	0.234142394	0.39
Pirttijärvensuo	14.543	0.252624672	0.299384301	0.67
Nimetönsuo4	14.543	0.252306181	0.142989517	0.32
Pykälistönsuo	14.543	0.236151402	0.144536981	0.31
Marketansuo	14.543	0.239225031	0.24244913	0.52
Kuvaslammensuo	14.543	0.240030851	0.265761546	0.57
Korvalammensuo	14.543	0.247780157	0.340361279	0.73
Karistonneva	14.543	0.24195139	0.317048862	0.68
Isosuo4	14.543	0.242419533	0.233124163	0.5
Raatesuo	14.544	0.206385934	0.192279614	0.38
Pirttisuo1	14.544	0.205691394	0.16516238	0.34
Penkkisuo	14.544	0.205691394	0.263912734	0.53
Moskuvansuo	14.544	0.205691394	0.164323023	0.33
Hirsisuo	14.544	0.207124603	0.200919982	0.4
Vehmassuo-Tervosuo	14.545	0.216721539	0.220970852	0.46
Rautosuo	14.545	0.216403048	0.259400565	0.54
Pieni Joensuo	14.546	0.243948673	0.275906185	0.58
Kalettomansuo	14.546	0.244904146	0.218822147	0.46
Mannissuo-Purnukorv	14.547	0.219394177	0.195005392	0.38
Jälsisuo-Konkarinsuo	14.548	0.261340002	0.32151294	0.61
Mökinsuo	14.548	0.324336925	0.079679693	0.14
Kypäräsuo	14.548	0.322696505	0.088216803	0.155
Palosuo	14.549	0.198555087	0.725085693	1.33
Velkkulansuo	14.549	0.241847784	0.191780641	0.32
Rumma	14.616	0.345657588	0.431552664	0.56
Parantaisensuo	14.624	0.021981627	0.245330857	0.54
Sarvisuo 1	14.624	0.174792022	0.186835368	0.35
Nimetönsuo5	14.624	0.174792022	0.309612896	0.58
Nimetönsuo3	14.624	0.178203328	0.091229629	0.17
Kuitulan Isosuo	14.624	0.179028334	0.527391656	0.91
Köpinneva-Kokkosuo	14.625	0.481276189	0.627766866	1.34
Koirasuo	14.625	0.554018741	0.181498623	0.39
Ahvensuo	14.625	0.429478251	0.150088919	0.31
Lamminsuo	14.626	0.590673013	0.144034842	0.3
Lampisuo1	14.628	0.200020913	0.375178009	0.65
Murtolamminneva	14.628	0.200020913	0.27822629	0.46
Perhonsuo	14.631	0.318077428	0.153260922	0.35
Haapapuukonsuot	14.632	0.253937008	0.257884798	0.73
Murtosuo1	14.633	0.135899679	0.176037627	0.37
Hepolamminneva	14.633	0.135826772	0.24021511	0.48
Töyrisuo1	14.642	0.339702192	0.230814175	0.41
Kyntöläisneva	14.644	0.220636483	0.12414047	0.3
Rummakonneva	14.646	0.11351706	0.293206441	0.66
Suurisuo5	14.647	0.109949387	0.135484185	0.3
Saarisuo A	14.647	0.109133973	0.265289863	0.49
Heposuo3	14.653	0.258530184	0.048930048	0.095
Porrassuo	14.656	0.147952449	0.171884796	0.41
Peurasuo	14.657	0.139856833	0.132888583	0.37
Heinäsuo5	14.657	0.242125984	0.378552883	1.054
Rokkasuo	14.658	0.258530184	0.207886168	0.54
Myllysuo	14.658	0.260170604	0.177088218	0.46
Tervasuo-Kangassuo	14.662	0.014218891	0.426808309	0.8
Partasuo	14.662	0.027564811	0.52305958	0.97
Rautasuo	14.663	0.105971129	0.116595442	0.31
Teerensuo	14.665	0.655695999	0.164135911	0.32
Soppisenneva	14.671	0.180930646	0.29182957	0.76
Ukonsuo	14.674	0.013779528	0.208438204	0.43
Korteniemi	14.687	0.00984252	0.078326052	0.24
Koiraneva	14.687	0.010170604	0.124695467	0.29
Kalalampi	14.687	0.010498688	0.11238254	0.255
Leukunneva	14.687	0.539534121	0.115119067	0.255

Name	Drainage basin	Value of the water area	Sensitivity score	Amount of peat
Soidinsuo	14.688	0.441437008	0.208444671	0.42
Rantinsuo	14.714	0.40209379	0.541575571	1
Pohjoissuo2	14.837	0.112204724	0.100474216	0.25
Lakeasuo	14.842	0.162073491	0.085514651	0.14
Martinsuo	14.843	0.336417515	0.142711195	0.325
Karasuo	14.844	0.329247632	0.250947675	0.48
Höystösensuo	14.844	0.332513123	0.618625305	1.18
Vetosuo	14.844	0.332513123	0.357530493	0.62
Pohjoissuo1	14.845	0.266076115	0.134379431	0.305
Teurisuo	14.954	0.148130881	0.178597508	0.34
Reinikansuo-Pahasuo	35.482	0.601213911	0.18656179	0.44
Luomussuo–Talvilahdenneva	35.482	0.598589239	0.207761994	0.49
Kilpisuo	35.482	0.588746719	0.309469577	0.72
Karjunneva	35.482	0.599245407	0.131441261	0.31
Ranta-Ahonsuo	35.483	0.357611549	0.1906004	0.49
Kivisuo 2	35.483	0.357611549	0.128363535	0.33
Isoneva2	35.483	0.678313648	0.144541606	0.31
Asemaneva	35.483	0.647145669	0.159271337	0.4
Raatosuo	35.483	0.395013123	0.158331473	0.33
Juurikassuo	35.483	0.395013123	0.345450487	0.72
Niinineva-Kurostenneva	35.483	0.340715223	0.295146915	0.7
Lehtosuo-Ojaneva	35.483	0.432906824	0.232905192	0.54
Kalmonsuo	35.483	0.489829396	0.180340798	0.37
Kuikkaneva	35.483	0.644425066	0.2540097	0.51
Kortesuo	35.484	0.099361483	0.145842296	0.35
Kankisuo	35.487	0.201145224	0.165042521	0.36
Isosuo2	35.487	0.205082232	0.201718636	0.44
Haleansuo	35.487	0.329560367	0.155091704	0.31
Ahvenneva	35.493	0.307266964	0.160353292	0.35
Karjosuo	35.626	0.014508603	0.285989231	0.69
Heposuo2	35.626	0.010084266	0.136777458	0.33
Nevalansuo	35.628	0.109580052	0.101944116	0.23
Linnasensuo	35.628	0.234580052	0.132970586	0.3
Valkeissuo	35.632	0.346167941	0.192991761	0.41
Leppäsuo	35.634	0.663593997	0.174317097	0.36
Olkitaipaleenneva	35.635	0.219233972	0.166050974	0.33
Sikolamminsuo	35.635	0.209280172	0.171184219	0.32
Sorvalinsuo	35.636	0.638157895	0.210753453	0.44
Pukkilamminsuo	35.636	0.574036661	0.320920031	0.67
Korhonsuo	35.637	0.670942311	0.237058297	0.5
Lehtosuo	35.638	0.729693328	0.144396279	0.3
Saikansuo	35.639	0.159488151	0.18373143	0.37
Riihisuo-Peurunsuo	35.639	0.160472403	0.164780054	0.33
Peurunsuo	35.639	0.208474352	0.248285716	0.5
Leinonneva	35.654	0.283046308	0.230496717	0.56
Sikosuo-Kantolansuo	35.654	0.283871314	0.157228038	0.38
Ottovuorenneva	35.654	0.283871314	0.390296578	0.93
Isoneva-Mäenperänsuo	35.654	0.320177357	0.194933413	0.47
Mustassuo	35.662	0.06117903	0.210495939	0.43
Lampisuo2	35.663	0.011154856	0.252828386	0.73
Konisuo-Kivisuo	35.663	0.010826772	0.210165419	0.6
Isosuo1	35.663	0.010826772	0.180096932	0.52
Amalianneva	35.663	0.010826772	0.19048714	0.55
Isoniitty	35.663	0.054461942	0.162772807	0.34
Pahkasuo	35.664	0.203294078	0.173513549	0.35
Pirttisuo-Karjosuo	35.673	0.416325152	0.375134163	0.79
Lauttasuo	35.674	0.374625869	0.232406919	0.61
Pihtisuo	35.674	0.373829642	0.451007702	0.95
Saarisuo1	35.675	0.41933163	0.28813136	0.83
Joutensuo	35.675	0.230750487	0.826451591	1.63
Loukkusuo	35.675	0.372068349	0.197739951	0.39
Niinisuo	35.677	0.023293963	0.1708589	0.32
Honkasuo	35.686	0.108678301	0.144716549	0.35
Saarisuo 2	35.686	0.114570383	0.164802451	0.33
Autionsuo	35.689	0.260826772	0.179004625	0.355
Isosuo6	35.764	0.11843832	0.158284658	0.32

References

Ewing Jr., P. L., W. Tarantino, G.S. Parnell. 2006. Use of decision analysis in the army base realignment and closure (brac) 2005 military value analysis. *Decision Analysis*, 3(1), 33-49.

Golabi, K., C. W. Kirkwood, A. Sicherman. 1981. Selecting a portfolio of solar energy projects using multi attribute preference theory. *Management Science*, 27(2), 174-189.

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

Liesiö, J., P. Mild, A. Salo. 2007. Robust portfolio modeling with incomplete cost information and project interdependencies. *European Journal of Operational Research*, 190, 679-695.

Liesiö, J. 2012. Measurable multiattribute value functions for portfolio decision analysis. *Manuscript*, (http://sal.aalto.fi/publications/pdf-files/mlie11.pdf, 18.02.2012).

Ollila, J. 2012. Portfoliomalli turpoeenoton optimointiin. *Bachelors thesis, Systems Analysis Laboratory, Aalto University*, (http://sal.aalto.fi/publications/pdf-files/toll12_public.pdf, 18.02.2012).