SUPPLEMENTARY MATERIAL

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Methods to inform the development of concise objectives hierarchies in Multi-Criteria Decision Analysis

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S-1 Material related to relevancy analysis

S-1-1. Introduction to relevancy analysis

The purpose of the relevancy analysis is to classify objectives into different categories. The results can be used to decide whether an objective needs to be included in the objectives hierarchy or MCDA modelling phase. The analysis is based on the assessment of importance of each objective in the decision context (Question 1) and on the differences in the impact of the alternatives on the objectives (Question 2).

Table 1 gives tentative guidance for answering the importance assessment questions (Question 1D in questionnaire, S-3-2).

Table 1. Evaluation criteria to assess the importance of the objective.

Importance scale	Criteria
Low	At least one of the following criteria is met and none of the criteria is in the categories "Moderate" or higher. • There are no particular economic, social, cultural or nature values related to the objective under consideration in the target area. • The objective is not sensitive to changes (example: increase in traffic noise near an airport) or recovers quickly from human pressure. • There are no regulations (e.g. legislation) concerning the use or state of the objective. • Objective is not a key concern to any of the stakeholders.
Moderate	At least one of the following criteria is met and none of the criteria is in the category "High": • Economic, social, cultural or nature values of the target area/receptor are of moderate importance to the objective under consideration. • The receptor's sensitivity is moderate. • There are no binding regulations concerning the use or state of the objective. • Local people or other stakeholders are moderately worried about the changes in the state of objective.
High	At least one of the following criteria is met: • Economic, social, cultural or nature values related to the objective under consideration are high. • The objective is sensitive to changes in the external environment and the recovery lasts long • There are binding regulations (e.g. legislation) concerning the use or state of the objective. • Local people or other stakeholders are worried about the changes in the status of objective.
Very high	At least one of the following criteria is met: • Economic, social, cultural or nature values related to the objective under consideration are very high. • The objective is very sensitive to changes in the external environment and the recovery lasts very long or does not happen at all. • There are very strict regulations (e.g. legislation) concerning the use or state of the objective. • Local people or other stakeholders are very worried about the changes in the state of objective. Conflicts are probable.
Unable to determine	There is not enough information to make the assessment.

The assessment of the alternatives´ impact ranges (Question 2A) is based on the difference between the worst and the best alternative with respect to intensity, spatial extent and temporal duration. The overall assessment takes differences in all these dimensions into account. For instance, the difference can be considered low if there is only small difference between the alternatives in all these criteria. If the difference in intensity, spatial extent or duration is large/very large, then the impact range can be considered high/very high.

The results of the analysis can be presented in a two-dimensional chart (Figure 1). The following conclusions are possible: Objectives, which belong to the "Low importance" and "Low impact range" category, can probably be excluded. It is worthwhile to consider the exclusion of the objectives if either importance or the impact range has a classification "Low". Uncertain cases are included in the further analysis (precautionary principle).

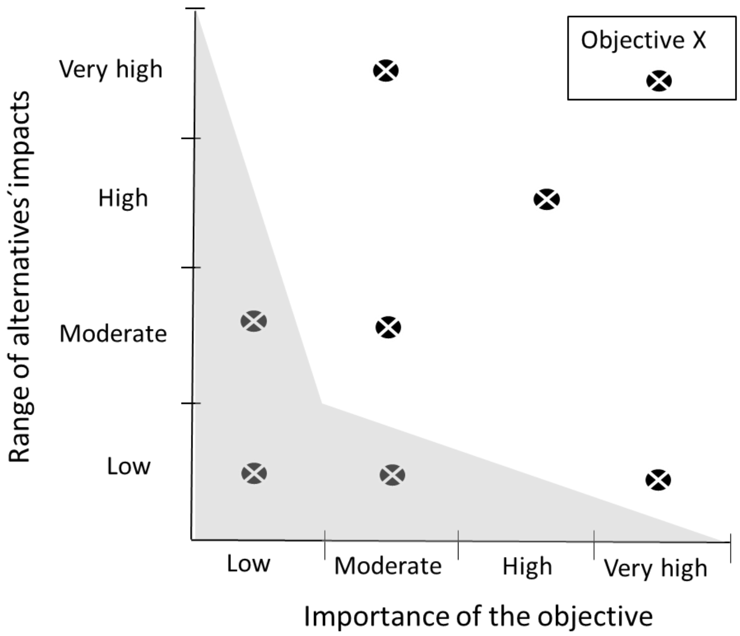


Figure 1. Comparison of the importance of the objective and its impact range (difference between the worst and the best alternative). It is worth considering the exclusion of the objectives located in the area with grey shading.

S-1-2 Feedback questionnaire of relevancy analysis

1. How easy was it to fill in the questionnaire?

a. objective's importance questions (questions 1a-d)?

☐ Easy ☐ Moderate ☐ Difficult ☐ Very difficult

b. alternatives' impact ranges question (question 2)

☐ Easy ☐ Moderate ☐ Difficult ☐ Very difficult

2. What was most difficult in answering and why?

3. How useful as a whole did you find the questionnaire in a better understanding of

a. objective's importance (Question 1)?

☐ Not useful ☐ Moderate ☐ Useful ☐ Very useful

b. alternatives' impact ranges (Question 2)

☐ Not useful ☐ Moderate ☐ Useful ☐ Very useful

4. Did you get any new ideas or insights when you were answering the questions, if so which?

5. Do you have any improvement ideas regarding the questionnaire?

☐ No ☐ Yes, which?

6. Did you miss more detailed instructions or impact information regarding the case to fill in the questionnaire?

☐ No ☐ Yes, which?

7. How much time did it take to fill in the questionnaire?

☐ <1 hour ☐ 1- <2 hours ☐ 2-<3 hours ☐ more than 3 hours, how long____

8. How familiar are you with the substance? You can choose more than one option.

☐ I know the basics ☐ Moderate experience/expertise ☐ Long experience/good expertise ☐ Other, what?____________ __________________

THANK YOU FOR YOUR VALUABLE CONTRIBUTION!

S-2 Material related to the Finnish land-use planning case (LUP)

S-2-1 Description of the LUP case

In Finland, almost third of the land area is covered by peatlands. About 51% of the Finnish peatlands have been drained for forestry, 4% for agricultural purposes, 32% are in a pristine/natural state, 12% protected and 0.6% (60.000 ha) are used for peat production. The use of peat as fuel and as a material for many other purposes has a long tradition in Finland. There has been a vivid debate about peat production in the area; on the one hand, there is a great need to increase domestic energy production in the region, but on the other hand, even the current peat production has significant adverse impacts on water courses and recreational use. This has resulted in a strong local opposition towards the development of new peat production areas.

The study was related to the preparation of the regional land use plan. The regional council of South Ostrobothnia region in Western Finland was drawing up a regional plan and one of its aims was to allocate 15 000 hectares of peatlands for peat production. The MCDA study assessed the relative risk for negative impacts in the catchments where the potential peat production areas are located. The results of the risk study together with nutrient load calculations are utilised in directing peat production to areas less sensitive for additional nutrient loading. The study area is presented in figure 1.

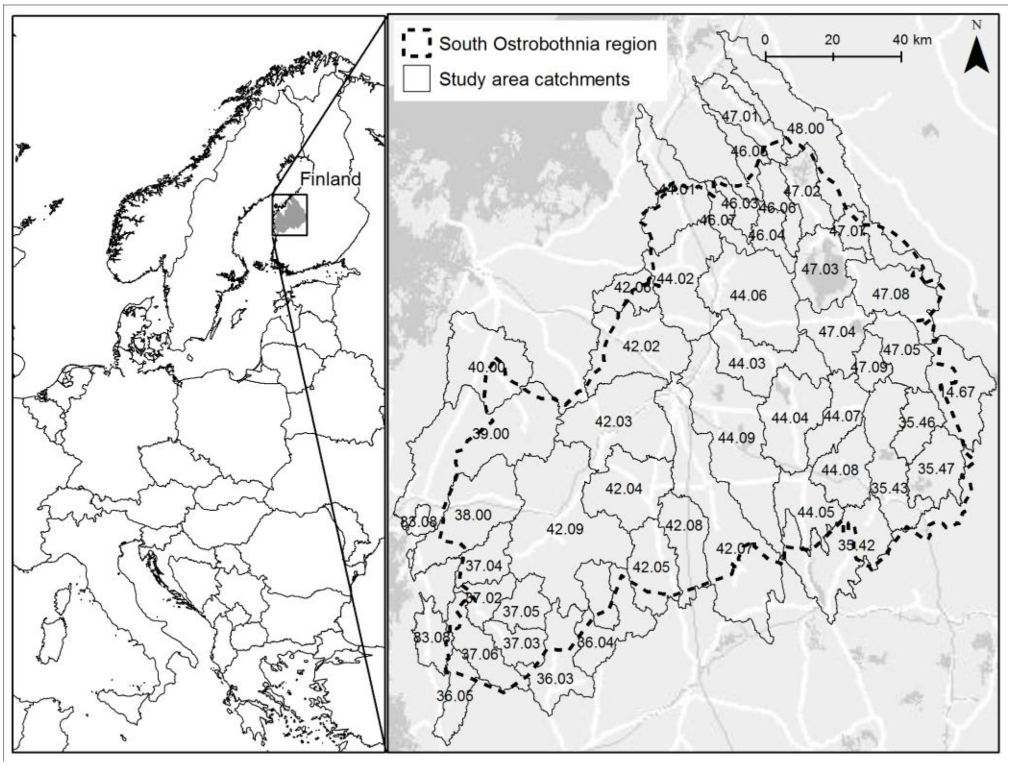


Figure 1. Map of the study area (Turo Hjerppe, SYKE).

The aim of the study was to find out differences between the catchment areas in order to direct the peat production to lower-risk areas. The assessment was relative and compared the catchments to each other as alternatives. The risk assessment was based on an assumption that the more water use values, protection values or sensitivity factors existed in the area (at the moment), the bigger the risk of negative impacts on watercourses would be. Producing information about the risk and its factors as well as ensuring stakeholder participation were also important objectives of the study.

The risk study began in January 2013 when the Regional Council of South Ostrobothnia and the working group comprised of consultants and researchers structured the framework for the assessment and drafted the value tree. Two workshops for the assessment group consisting of stakeholder groups' representatives were arranged to define the value tree and to set importance weights. After this phase the measurement data on the criteria data was collected and analysed. The assessment group assembled once again to discuss about the value functions and the working group calculated the results. Finally, a seminar was held to present the results to the stakeholders and the results were reported (Fig. 2).

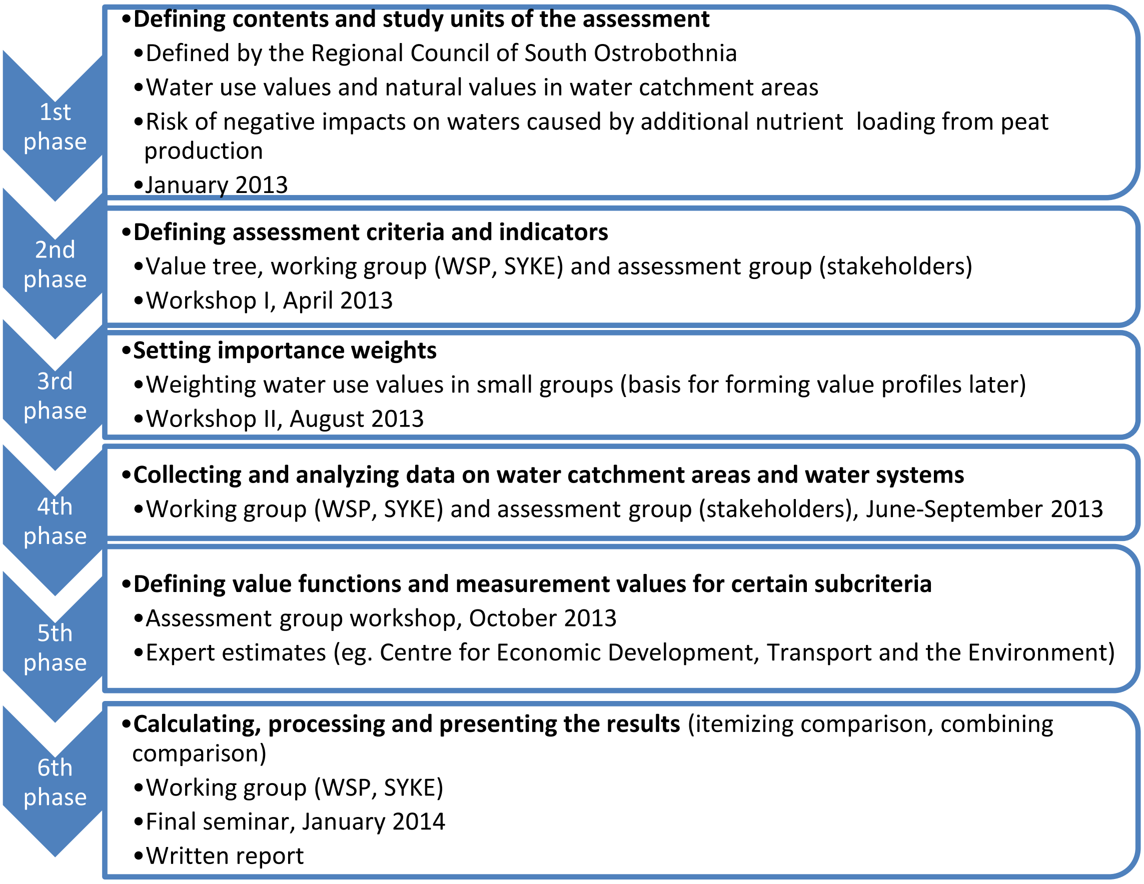


Figure 1. The phases of the evaluation process (Anna-Mari Lehmonen)

S-2-2. Description of the objectives and their impact ranges in the LUP case.

S-2-1. Evaluation of the impact ranges of the alternatives: What is the difference in the impacts in two situations; (i) new peat extraction area is placed on the catchment where the impact is smallest and (ii) largest? Scale: * Low, ** Moderate, *** High, NR=Not relevant

Objective	Abbreviation	Attribute	Description/comments	Minimum value	Maximum value
Natura 2000 areas	Natura_2000	Proportion of Natura 2000 nature protection areas in the catchment (%)	Natura 2000 areas connected to water locate in 18 of 48 catchments in the target area.	0	15
Endangered species	End_species	River pearl mussel	River pearl mussel exists only in four of 48 catchments in the target area.	No	Yes
Condition of beds, banks and shores	River_morph	Weighted average of hydrologic and morphologic modification of water bodies (1=Poor-5=Excellent)	The morphological naturalness is a proxy attribute to estimate the biodiversity of aquatic flora and fauna (excluding fish, crayfish and river pearl mussel). Many species are sensitive to chaneges in suspended material, dissolveld oxygen, quality of sediment and ph.	1	5
Ecological status	Eco_status	Weighted average of ecological status of water bodies (classification 1 to 5: excellent condition 5, poor condition 1)	Changes in chemical water quality deteriorate biological status as well.	1	4.5
Acidity/ alkalinity	Acid_target	A target set for water acidity reduction, or the occurrence of acid sulphate soils (yes/no)	The acidity of the water is directly and negatively affected by the loading from the peat extraction areas.	No	Yes
Water colour	Water_col	Water turbidity (FNU)	The criterion is used to assess the sensitivity of the waterbody to additional loading. Very large differences in the amounts of solid articles.	0.6	47.3
Turbidity of water	Water_turbid	Colour of water (mg Pt/l)	The criterion is used to assess the sensitivity of the waterbody to additional loading. The difference of clear and most turbid watershed is extremely large.	8	381
Retention of water	Hydr_retention	Water turnover (0=Small, 1=Fast) based on run-off and proportion of catchment basin covered by lakes	The criterion is used to assess the sensitivity of the waterbody to additional loading.	0	1

Objective	Abbreviation	Attribute	Description/comments	Minimum value	Maximum value
Summer houses' recreational use	Summer_houses	Density of buildings at the water front/km^2	The recreational use of summer houses is versatile including swimming, fishing, water intake for irrigation purposes.	0	1
Swimming	Swimming	Number of public beaches	Large difference in the number of public beaches. Direct contact with water when swimming.	0	8
Tourism	Tourism	Importance to tourism (0=No, 3 high)	Water related tourism, such as canoeing and hiking by water courses.	0	3
Potential for recreational use	Pot_recreation	Population density/km^2	Population density describes the potential for recreational use.	0.92	48.2
Water supply (industry, municipalities)	Water_supply	0=No, 1=Yes	E.g. the City of Seinäjoki (pop. 60 000) is dependent on the water supply from the River Seinäjoki. The costs of water purification increase if the there are more suspended material in the raw (source) water.	0	1 (City of Seinäjoki)
Fishery	Fishery	Overall value (four classes) based on fish stocks, valuable fish species, crayfish, professional and recreational fishing	Most valuable fish species (e.g. trout) and crayfish are sensitive to the changes in water and sediment quality. The differences in the value of river fisheries in the target area are very large.	1	4
Waterfowl hunting	Waterfowl	Catchment's importance for hunting (1=Low - 4=very high)	Changes in the habitats of waterfowls.	1	4
Flood risks	Flood	Existence of significant flood risk areas (0=No, 1=Yes)	Increase in maximum flows.	0	1

S-2-3. Example of the relevancy analysis questionnaire in the LUP case.

OBJECTIVE 1: NO HARM TO RECRETIONAL USE OF SUMMER HOUSES

ATTRIBUTE: Density of buildings at the water front/km^2

1. **IMPORTANCE OF THE OBJECTIVE IN THE CONSIDERED CATCHMENT AREA S**

   A. **Are there nature, social or economic values related to the objective and what is their importance?**

	Not relevant/ None	Low	Moderate	High	Unable to determine
Nature values	☐	☐	☐	☐	☐
Social values	☐	☐	☐	☐	☐
Economic values	☐	☐	☐	☐	☐

   B. **Are there international, national, regional (county) or local (municipality) level regulations (e.g. legislation or recommendations) related to the objective and how strict they are?**

	No	No binding regulations	Binding regulations	Unable to determine
International	☐	☐	☐	☐
National	☐	☐	☐	☐
Regional	☐	☐	☐	☐
Municipality	☐	☐	☐	☐

   C. **How important is it to improve the achievement of the objective or prevent the deterioration of its achievement in the catchment area?** When giving your estimate take into account your answers to the questions 1A and 1B.

   Not important ☐ Slightly ☐ Moderately ☐ Important ☐ Very important ☐ Unable to determine ☐

Arguments:

2. **DIFFERENCE IN THE IMPACT RANGE OF THE CATCHMENT AREAS**

   A. **What is the sensitivity of the objective to the estimated changes the project can cause in environmental conditions?**

   Low ☐ Moderate ☐ High ☐ Unable to determine ☐

   B. **How large is the difference between the minimum and maximum values of the catchment areas with regard to the objective?** When giving your estimate take into account your answer to the question 2A and

   - compare situations that a new peat extraction site is placed on the catchment where the attribute gets the minimum value and that it is placed on the catchment where objective gets the maximum value.
     i. **Minimum value: 0.23 summer houses/km^2**
     ii. **Maximum value: 19.6 summer houses/km^2**

   Low ☐ Moderate ☐ High ☐ Very high ☐ Unable to determine ☐

Arguments:

S-2-4. Objectives‘ weights in different viewpoints in the LUP case.

Objectives	**Viewpoint 1** Emphasises nature and sensitivity of waters	**Viewpoint 2** Balanced: environment and water use almost equal weights	**Viewpoint 3** Emphasises water uses	**Viewpoint 4** Like viewpoint 2 but zero weight to “problematic objectives”	**Viewpoint 5** Emphasises strongly water uses
Water use, total	**0.30**	**0.52**	**0.70**	**0.60**	**0.85**
Summer houses	0.02	0.07	0.06	0.07	0.17
Public swimming places	0.03	0.04	0.06	0.07	0.14
Tourism	0.03	0.06	0.06	0.08	0.14
Potential recreational use	0.02	0.02	0.05	0.00	0.00
Fishery	0.12	0.19	0.23	0.21	0.30
Water supply	0.09	0.15	0.23	0.17	0.11
Aquatic environment, total	**0.70**	**0.48**	**0.30**	**0.40**	**0.15**
NATURA 2000 areas	0.08	0.08	0.05	0.09	0.04
Endangered species	0.08	0.08	0.04	0.09	0.04
Beds, banks and shores	0.07	0.02	0.03	0.02	0.00
Hydraulic retention	0.09	0.04	0.01	0.00	0.02
Water colour	0.07	0.05	0.03	0.11	0.02
Water turbidity	0.07	0.05	0.03	0.11	0.02
Ecological status	0.12	0.05	0.03	0.00	0.00
Acidification target	0.12	0.09	0.09	0.00	0.00

S-2-5 Results from the Finnish land use planning case (LUP)

The relevancy analysis questionnaire was completed by a Finnish consultant responsible for the original MCDA case. Five objectives were placed in the highest classes for both the importance and the impact range (top-right square in Fig. 1): Recreational use of summer houses, Fishery, Natura 2000 areas, Endangered species and Ecological status. Their achievement depends strongly on water quality. Recreational use of summer houses is also important for the Finnish lifestyle and the monetary investments in properties can be high. All impacts of peat extraction on Waterfowl hunting and Flood risk were considered very small and consequently their impact ranges were also low (bottom row). However, in general Flood risk as an objective was considered “very important” because the study area is regularly partly inundated. It is noteworthy that Waterfowl hunting and Flood risk were finally excluded also from the original hierarchy. Thus, our relevancy analysis confirmed the choice made in the original project and the analyses did not suggest us to consider removing any of the objectives from the objectives hierarchy. It should be noted that this analysis is structured but subjective and therefore other evaluators might have come to different conclusions.

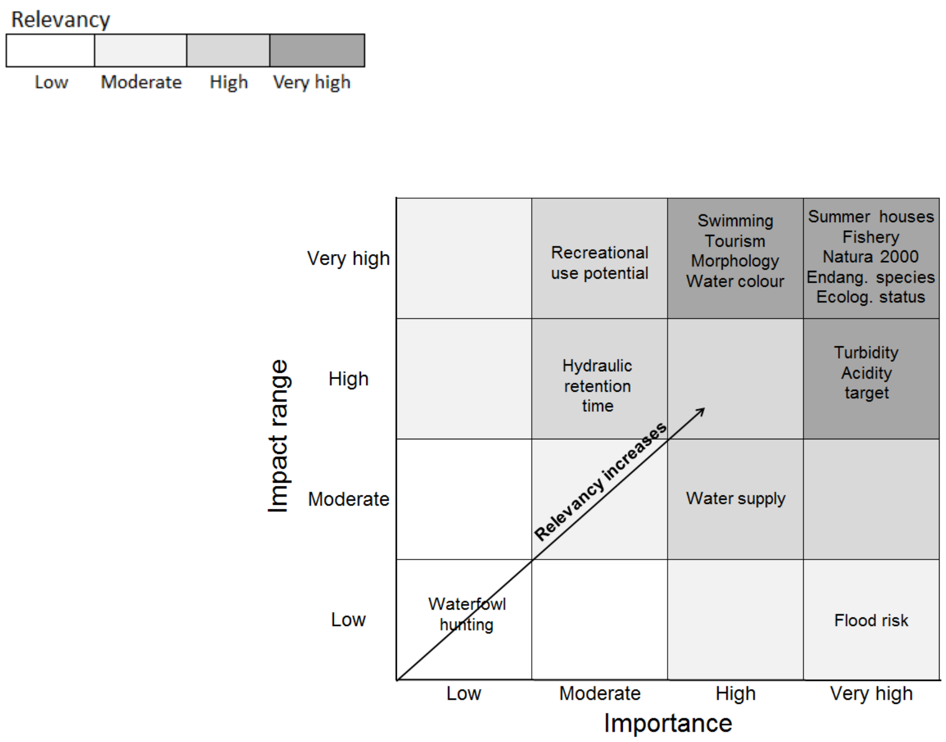


Figure 1. Results of the relevancy analysis in the LUP case.

The strongest positive correlations of 0.5, were between the Recreational use of summer houses and Swimming, and between Fishery and Water color (Fig. 2). The first correlation arises because most summer houses and public swimming beaches are located near large lakes. The strongest negative correlation between Hydraulic retention time and Recreational use potential (-0.6) is an artifact; we could not find any causality or sensible explanation. There were two times more positive (14) than negative correlations (7). Overall, according to the correlation analysis there was no need to eliminate or combine objectives. In the PCA, the decision alternatives are scattered indicating that there is a large variation in the characteristics of the 48 analysed watersheds (Fig. 3). The loadings of the objectives on the first two principal components is rather different, reflecting the overall weak correlations. This suggests that the objectives highlight different characteristics of the alternatives and are useful for distinguishing between alternatives.

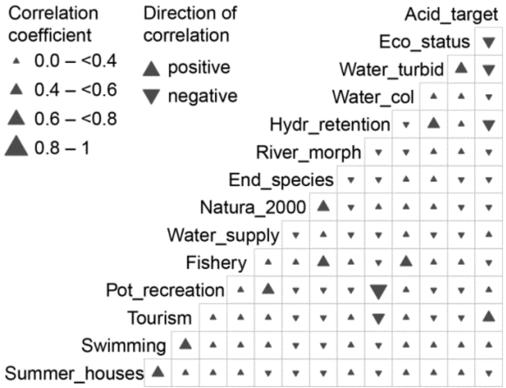


Figure 2. Results of the correlation analysis for the LUP case.

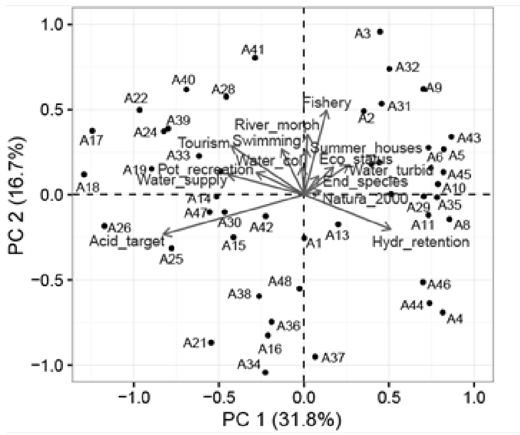


Figure 3. Results of the PCA for the LUP case. A1–A48 are the watersheds (= decision alternatives). Dots: the alternatives' PCA scores on the first two components. Arrows: the PCA loadings of objectives on the components. The longer an arrow, the higher is the loading on that component.

We analysed the sensitivity of the results to the weights of the lowest-level objectives (see 2.3.4) based on the changes in rankings of those five watersheds that were most/ least impacted by additional pollution loading. The ranking was most sensitive to changes in the weights of Water supply (Fig. 4) and Endangered species; four of the top-five watersheds changed their rank. The outcome was least sensitive to changes in weights of Swimming, Fishery and Water colour (S-2-6). Comparing the results of the sensitivity analysis to those of the relevancy analysis can give further insights whether an objective can be excluded. However, in the LUP case, this did not produce new insights because in the relevancy analysis there were no borderline cases.

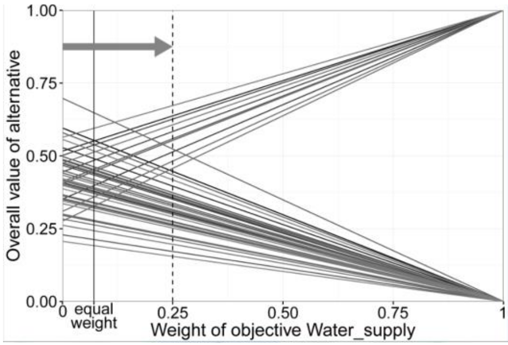


Figure 4. Example of the local sensitivity analysis in the LUP case with respect to Water_Supply. Lines: overall values of 48 watersheds when weight of objective (here water supply) varied between 0 and 1. For all other objectives equal weights were assigned.

The relevancy analysis and statistical analyses did not suggest us to consider removing any of the objectives from the original hierarchy of the Finnish LUP. However, because we also aimed at analysing how sensitive the results are to the size of the hierarchy, we developed three simpler hierarchies. Hereby, we eliminated those objectives which were either considered most problematic in the original study in terms of defining the shape of the marginal value functions (Ecological status[1]) or for which the ability to measure the sensitivity of water bodies in practice was questioned. The revised hierarchies (REV-Hs) deviated from the original hierarchy as follows:

- REV-H1: Ecological status was excluded.
- REV-H2: Hydraulic retention time, Water colour and Turbidity of water were excluded.
- REV-H3: Combination of options 1 and 2. Four objectives were excluded.

Using the weights of viewpoints 1–5 (which represent different weight allocations (S-2-4)) the average change in rank position for the ten watersheds which had obtained the highest overall impact scores in the original hierarchy was calculated for each viewpoint. The changes were largest in viewpoint 1, which gave a high weight to Nature values and Sensitivity of waters, and smallest in viewpoint 5, which assigned the highest weights to Recreational use and Fishery (Fig. 5). However, even in the most sensitive viewpoint 1, nine of the top-ten watersheds were the same as in the original hierarchy (S-2-9). In viewpoints 3–5, there were no differences between Rev-H2 and Rev-H3. The

[1] Some stakeholders commented that it is more important to protect water bodies with a good or excellent ecological status than those with a poor or satisfactory status. However, there were also different opinions stating that establishing new peat extraction sites in the watersheds which are currently in a poorer state is no longer acceptable, because the requirements to improve water quality apply also to those watersheds.

reason is that the only input difference between Rev-H2 and Rev-H3 was Ecological status, which had received zero or a very low weight of 0.03 in the original analysis.

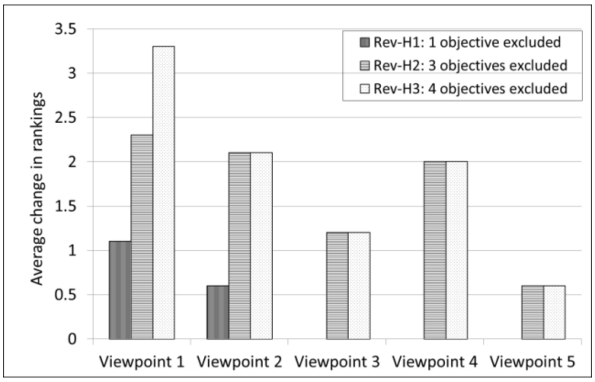
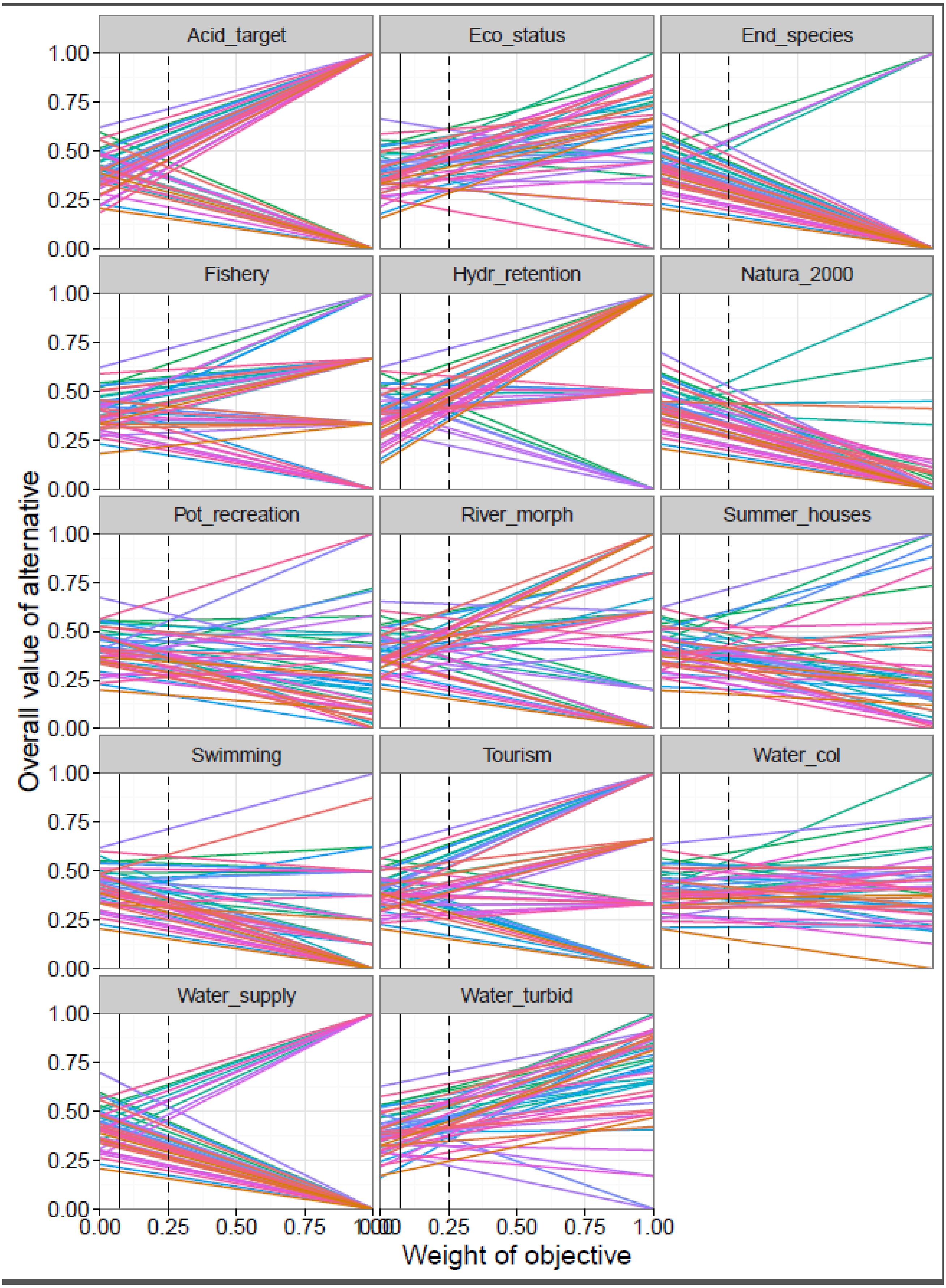


Figure 5. Average changes in the rankings of ten watersheds compared to the original study in three objectives hierarchy options in the LUP case. Those ten watersheds that had obtained the highest risk values in the original study were included here. In each option, the difference in watershed position compared to the original hierarchy was calculated.

S-2-6. Results of local sensitivity analysis in the LUP case.

The lines describe the overall values of 48 watersheds when an objective's weight varies from 0 to 1. Other objectives' weights were equal in the calculations.



S-2-7. Summary of the local sensitivity analysis in the LUP case

Changes in alternatives rankings if the weight of each objective is changed from 0 to 0.25.

	Changes in best alternative	**Changes in alternatives in Top5** [1]	**Changes in worst alternative**	**Changes in alternatives in bottom5** [1]
Natura 2000 areas	Yes	Yes (3/5)	No	No (5/5)
Endangered species	Yes	Yes (1/5)	No	No (5/5)
Condition of beds, banks and shores	No	Yes (4/5)	No	Yes (3/5)
Ecological status	Yes	Yes (4/5)	Yes	Yes (4/5)
Reduction of acidification	No	Yes (3/5)	Yes	Yes (2/5)
Water colour	No	Yes(4/5)	No	Yes (4/5)
Turbidity of water	No	Yes(4/5)	Yes	Yes (2/5)
Hydraulic retention time	No	Yes (2/5)	Yes	Yes (1/5)
Summer houses	No	Yes (2/5)	No	Yes (5/5)
Swimming	No	Yes (4/5)	No	No (5/5)
Tourism	Yes	Yes (3/5)	No	Yes (2/5)
Potential for recreational use	Yes	Yes (4/5)	No	Yes (3/5)
Water supply	Yes	Yes (0/5)	No	Yes (4/5)
Fishery	No	Yes(5/5)	Yes	Yes (4/5)

[1] Number of alternatives retaining the same when the weight of objective is 0 and 0.25

S-2-8. Sensitivity index in the LUP case.

	Changes in best alternative	Changes in Top5	Changes in worst alternative	Changes in Bottom5	Sensi-tivity index[1]
	Yes =0.25 No =0	One alternative changes =0.1	Yes =0.1 No=0	One alternative changes =0.05	
Natura 2000 areas	0,25	0,2	0	0	0,45
Endangered species	0,25	0,4	0	0	0,65
Condition of beds, banks and shores	0	0,1	0	0,1	0,2
Ecological status	0,25	0,1	0,1	0,05	0,5
Reduction of acidification	0	0,2	0,1	0,15	0,45
Water colour	0	0,1	0	0,05	0,15
Turbidity of water	0	0,1	0,1	0,15	0,35
Hydraulic retention time	0	0,3	0,1	0,2	0,6
Summer houses	0	0,3	0	0,25	0,55
Swimming	0	0,1	0	0	0,1
Tourism	0,25	0,2	0	0,15	0,6
Potential for recreational use	0,25	0,1	0	0,1	0,45
Water supply	0,25	0,5	0	0,05	0,8
Fishery	0	0	0,1	0,05	0,15

[1]Calculated by summing up the values in the columns which describe the changes in best and worst alternatives.

Sensitivity classes

<=0.3	*	Low
0.3- <0.6	*	Moderate
0.6-	*	High

S-2-9. Major findings in the LUP case on the basis of relevancy analysis (RA), correlation analysis (CA), principal component analysis (PCA) and sensitivity analysis (SA)

Objectives	Methods RA[1]	CA/PCA[2]	SA[3,4]	Comments
Water use				
Summer houses	****	Swimming (+)	**	Combining with Swimming is not sensible because they describe different types of recreational use and are not overlapping
Swimming	****	Summer houses (+)	*	See Summer houses
Tourism	****		***	
Recreational use potential	***		**	
Fishery	****	Water colour (-)	*	See Water colour
Water supply	**		***	Needs special attention in weight elicitation
Waterfowl hunting	*		NA[5]	Can be excluded from the hierarchy (Note: was excluded from the original hierarchy)
Flood risk	*		NA[5]	Can be excluded from the hierarchy (Note: was excluded from the original hierarchy)
Aquatic environment				
NATURE 2000 areas	****		**	
Endangered species	****		***	Needs special attention in weight elicitation
Condition of beds, banks and shores	****		*	
Ecological status	****		**	
Reduction of acidification	****		**	
Water colour	****	Fishery (-)	*	There is causality between objectives but their combination is not justified because Water colour describes sensitivity of the watershed in broader sense.
Turbidity of water	****		**	
Hydraulic retention time	***		***	

[1] Scale : Very high ****, High ***, Moderate **, Low *

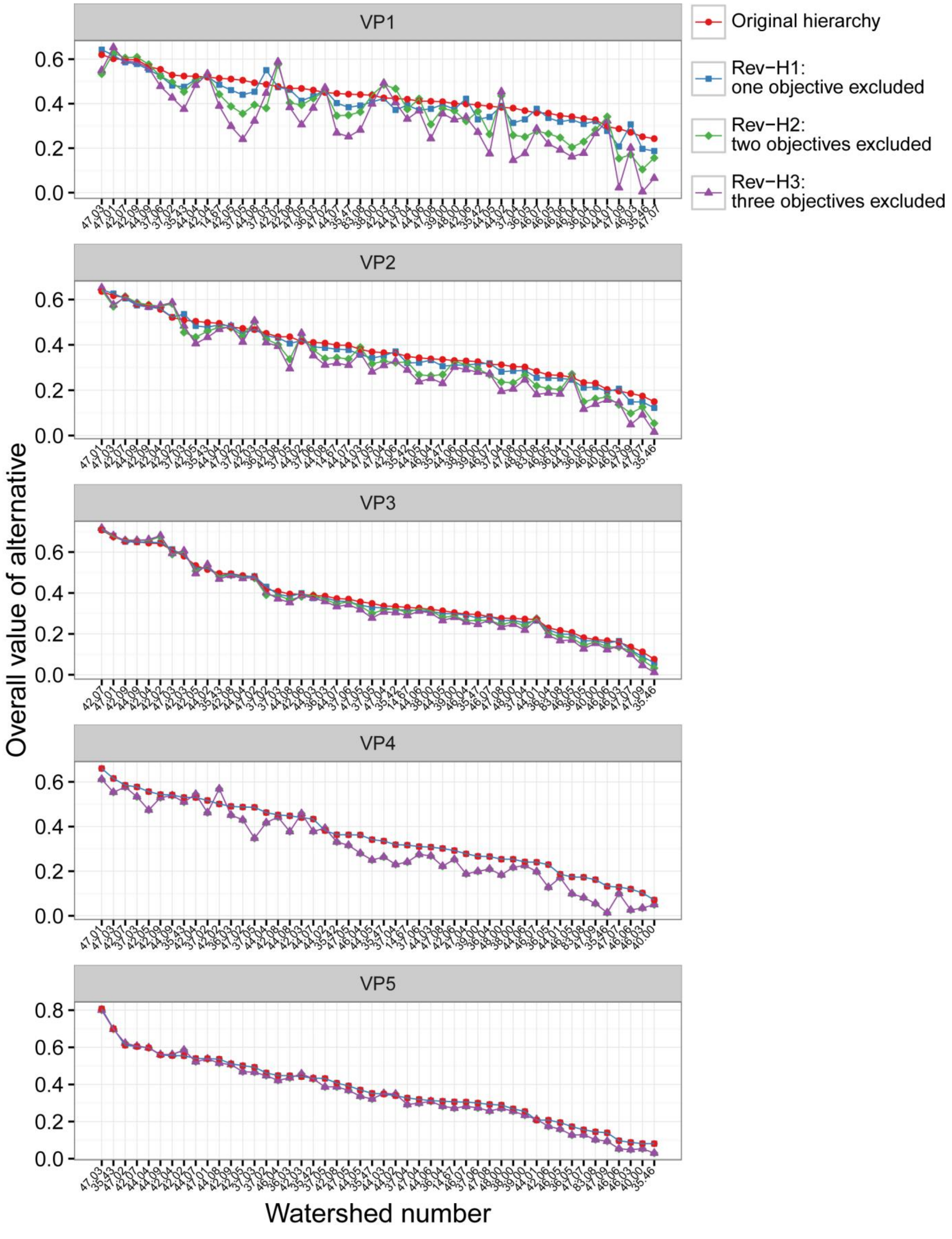
[2] Only strongest and meaningful correlations are indicated and the direction of correlation; positive (+), negative (-).

[3] Scale: High ***, Moderate **, Low *

[4] Local sensitivity analysis aimed to identify which objectives are most/least responsible for changing the ranking order of alternatives (see Table S-2-X).

[5] NA not included in the original hierarchy and therefore was not included in the sensitivity analysis.

S-2-10. The impacts of the objectives hierarchy options on the overall values of alternatives in five viewpoints (VP) in the LUP case.



S-3. Material related to Swiss wastewater infrastructure case (SWIP)

S-3-1 Example of relevancy analysis questionnaire in the SWIP case

OBJECTIVE: Good chemical state of water-courses

Attribute: Average water quality across all reference points in catchment [0-1]

A good wastewater infrastructure protects surface and ground water. Surface water is in a good chemical state if the concentration of nutrients and pesticides does not exceed certain water quality limits at all reference points in the catchment Mönchaltorfer Aa.

Currently, the chemical state of the watercourse is ‘good’ in the case study area Mönchaltorfer Aa, and the average value of the water quality indicator of all reference points in catchment is 0.61.

Worst case: The average value of the water quality indicator of all reference points in catchment is 0.56.

Best case: The average value of the water quality indicator of all reference points in catchment is 0.76.

Source: Zheng et al. 2016.

1. IMPORTANCE OF THE OBJECTIVE **"Good chemical state of water-courses"** IN THE STUDY AREA

A. Are there nature, social or economic values related to this specific objective and what is their importance? Values which are associated with the other objectives in the hierarchy should not be considered to avoid double-counting.

	Not relevant/ None	Low	Moderate	High	Unable to determine
Nature values	☐	☐	☐	☐	☐
Social values	☐	☐	☐	☐	☐
Economic values	☐	☐	☐	☐	☐

Comment:

B. Are there international, national, cantonal or municipality level regulations (e.g. legislation or recommendations) related to the objective and how strict are they?

	No	Non-binding regulations	Binding regulations	Unable to determine
International	☐	☐	☐	☐
National	☐	☐	☐	☐
Cantonal	☐	☐	☐	☐
Municipality	☐	☐	☐	☐

Comment:

C. How vulnerable or susceptible is the receptor (here water course)**?** What is the ability of the receptor to tolerate changes? Are there any particularly sensitive targets in the study area?

Low ☐ Moderate ☐ High ☐ Unable to determine ☐

Comment:

D. How important is it to improve the achievement of the objective or prevent the deterioration of its achievement in the study area from the current state? When giving your estimate take into account your answers to the questions 1A-1C.

i. Improvement of the achievement of the objective

Not important ☐ Slightly ☐ Moderately ☐ Important ☐ Very important ☐ Unable to determine ☐

ii. Prevention of the deterioration of the objective

Not important ☐ Slightly ☐ Moderately ☐ Important ☐ Very important ☐ Unable to determine ☐

Comment:

2. DIFFERENCE IN THE IMPACT RANGE

A. How large is the difference between the worst and best cases with regard to the objective? When giving your estimate take also into account if there are differences in the spatial extent or duration of the alternatives' impacts.

   i. Worst case: The average value of the water quality indicator of all reference points in catchment is 0.56.

   ii. Best case: The average value of the water quality indicator of all reference points in catchment is 0.76.

Low ☐ Moderate ☐ High ☐ Very high ☐ Unable to determine ☐

Comment:

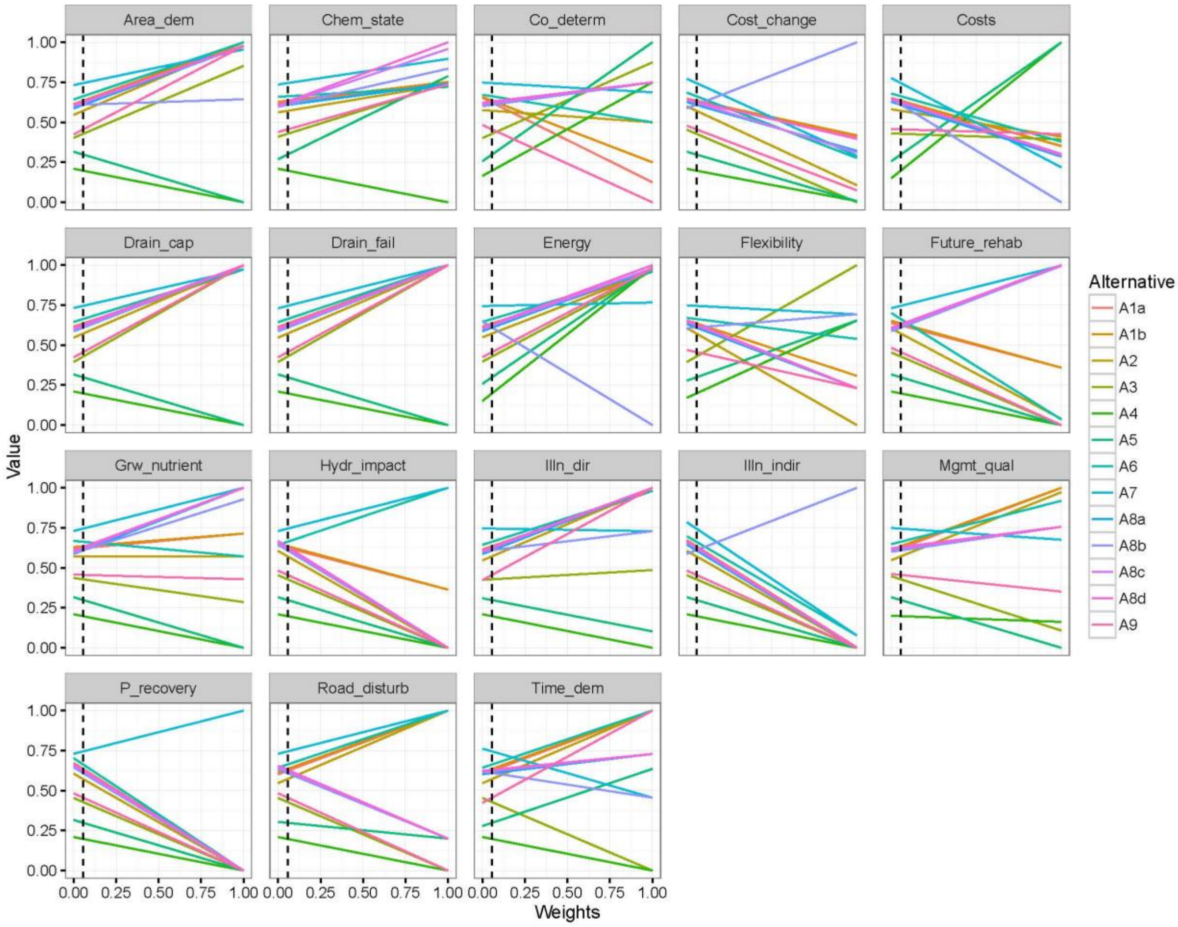
S-3-2. Stakeholders (SHs) rescaled weights to objectives in the SWIP case.

Source: Zheng et al. (2016)

	SH1	SH2	SH3	SH4	SH5	SH6	SH7	SH8	SH9	SH10
Area_dem	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Chem_stat	0.00	0.17	0.01	0.02	0.15	0.15	0.07	0.10	0.03	0.05
Co_determ	0.01	0.13	0.00	0.00	0.00	0.02	0.00	0.01	0.02	0.00
Cost_change	0.00	0.02	0.01	0.03	0.00	0.00	0.02	0.00	0.01	0.01
Costs	0.06	0.02	0.04	0.03	0.02	0.20	0.12	0.08	0.10	0.09
Drain_cap	0.00	0.00	0.04	0.00	0.03	0.02	0.03	0.00	0.04	0.01
Drain_fail	0.00	0.05	0.06	0.05	0.03	0.06	0.21	0.17	0.11	0.22
Energy	0.01	0.02	0.01	0.00	0.02	0.05	0.03	0.02	0.02	0.01
Flexibility	0.07	0.02	0.07	0.06	0.12	0.04	0.02	0.14	0.02	0.03
Future_rehab	0.73	0.21	0.62	0.48	0.14	0.16	0.15	0.17	0.15	0.23
Grw_biocide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grw_nutr	0.01	0.08	0.01	0.03	0.02	0.04	0.04	0.05	0.04	0.02
Hydr_impact	0.01	0.01	0.00	0.01	0.01	0.01	0.03	0.01	0.01	0.00
Illn_dir	0.00	0.00	0.04	0.01	0.02	0.02	0.09	0.09	0.25	0.15
Illn_indir	0.04	0.09	0.02	0.09	0.37	0.04	0.03	0.03	0.08	0.05
Mgmt_qual	0.03	0.01	0.01	0.01	0.01	0.05	0.02	0.06	0.07	0.10
P_recovery	0.00	0.15	0.02	0.04	0.05	0.03	0.05	0.04	0.01	0.02
Road_disturb	0.01	0.02	0.03	0.11	0.01	0.10	0.01	0.00	0.02	0.01
Time_dem	0.00	0.01	0.01	0.02	0.00	0.01	0.08	0.03	0.01	0.01

S-3-3. Results of local sensitivity analyses in the SWIP case.

The lines describe the overall values of alternatives when an objective's weight varies from 0 to 1. Other objectives' weights were equal in the calculations.



S-3-4. Summary of the local sensitivity analysis and the sensitivity index in the SWIP case.

Changes in alternatives rankings if the weight of each objective is changed from 0 to 0.25.

Objectives	Abbre-viations	Changes in best alternative(s) Top5[1]	Top1	One alternative changes in Top5 =0.1	Change in the best alternative =0.25	Sensitivity index
Low future rehabilitation burden until 2050	Future_rehab	1	No	0.1		0.1
Flexible system adaption	Flexibility	2	No	0.2		0.2
Good chemical state of water-courses	Chem_stat	2	No	0.2		0.2
Low negative hydraulic impacts on surface water	Hydr_impact	1	No	0.1		0.1
Low contamination of ground water from sewers	Grw_nutrient	2	No	0.1		0.1
Low contamination from infiltration structure	Grw_biocide					0
Recovery of nutrients	P_recovery	0	No			0
Efficient use of electrical energy	Energy	1	No	0.1		0.1
Few gastro-intestinal infections through direct contact with wastewater	Illn_dir	0	No			0
Few gastro-intestinal infections through indirect contact with wastewater	Illn_indir	1	Yes	0.1	0.25	0.35
Few structural failures of drainage system	Drain_fail	0	No			0
Sufficient drainage capacity of drainage	Drain_cap	0	No			0
High quality of management and operations	Mgmt_qual	0	No			0
High co-determination of citizens in infrastructure decisions	Co_determ	2	No	0.2		0.2
Low time demand for end users	Time_dem	1	Yes	0.1	0.25	0.35
Low additional area demand for end users	Area_dem	0	No			0
Low unnecessary construction and road works	Road_disturb	3	No	0.3		0.3
Low annual costs	Costs	0	No			0
Mean annual increase of costs	Cost_change	1	Yes	0.1	0.25	0.35

[1] Number of alternatives retaining the same ranking when the weight of objective is 0 and 0.25

Sensitivity classes		
<0.2	*	Low
0.2-<0.4	*	Moderate
0.4-	*	High

S-3-5. Major findings in the SWIP case on the basis of relevancy analysis (RA), correlation analysis (CA), local sensitivity analysis (SA) and means-ends objectives network analysis.

Objectives	Abbreviations	Methods				Comments	Recommendation
		RA[1]	CA/PCA[2]	SA[3]	Means-ends network/analysis		
Low future rehabilitation burden until 2050	Future_rehab	****	Grw_nutrient (0.9)	**	…	Influences pipe condition which in turn influences many other objectives. However, focus on future generations.	Keep, relevant decision dimension as future generation aspect is not taken into account by other objectives.
Flexible system adaption	Flexibility	***	Time demand (-0.8)	*(*)			Keep, represents one special decision dimension.
Good chemical state of water-courses	Chem_stat	****		**			Keep, represents one special decision dimension.
Low negative hydraulic impacts on surface water	Hydr_impact	**		*		Combination to chem_stat would be artificial because objectives have different nature: continuous loading vs. storm related events	Keep, represents one special decision dimension.
Low contamination of ground water from sewers	Grw_nutrient	*	Future_rehab (0.9) Drain_fail, Drain_cap, Illn_dir (0.8)	*(*)		Depends on sewer condition like the other objectives it's correlated with.	Low difference between alternatives, probably not relevant in this decision context.
Low contamination from infiltration structure	Grw_biocide	*	Not included	Not		No difference between alternatives.	Not relevant in this decision context.
Recovery of nutrients	P_recovery	***		*		Only one alternative different.	To be discussed if really relevant in this decision context =>Important dimension to be included.
Efficient use of electrical energy	Energy	**		*	Means objective, relates to costs? And also to climate?	The percentage of total energy consumption is very small and also the monetary value of the energy save is relatively small, ca 60 CHF/year. According to ElCom, private customers will pay 20.6 cents per kWh in 2016.	Could be excluded; climate impact negligible (electricity produced by hydro power in Switzerland).
Few gastro-intestinal infections through direct contact with wastewater	Illn_dir	****	Drain_cap , Drain_fail (0.9), Area_dem, Mgmt_qual, grw_nutrient (0.8) Forms one cluster with Drain_cap , Drain_fail, Area_dem, Mgmt_qual,	*		Health risk? Is it possible to combine with Illn_indir? Two different infection pathways that are affected differently by alternatives	Very relevant (if predictions are true). Think about combination with health risks from indirect exposure.

Objectives	Abbreviations	Methods				Comments	Recommendation
Few gastro-intestinal infections through indirect contact with wastewater	Illn_indir	**	Cost_change (0.8)	**(*)		Health risk? Is it possible to combine with Illn_dir?	If only overall health risks are of importance, it maybe can be combined.
Few structural failures of drainage system	Drain_fail	****	Drain_cap (1.0), Illn_dir (0.9), Grw_nutr (0.8)	*	Means, for flooding, damage, health impacts.	Covers dimensions which are not included in the other objectives. No double-counting.	Include in the analysis.
Sufficient drainage capacity of drainage	Drain_cap	***	Drain_fail , Area_dem (1), Illn_dir (0.9), Grw_nut (0.8). Forms one cluster with Area_dem , Drain_fail, Illn_dir, Mgmt_qual	*	Means, for flooding, damage, disturbance, health impacts.	Covers dimensions which are not included in the other objectives. No double-counting.	Include in the analysis.
High quality of management and operations	Mgmt_qual	*	Illn_dir (0.8). Forms one cluster with Area_dem , Drain_fail, Illn_dir, Drain_cap	*	Means objective	Internal factor included in the scenarios. The quality of management should reflect on structural failures, for instance. Risk of double-counting.	Could be excluded.
High co-determination of citizens in infrastructure decisions	Co_determ	**		**		Internal factor included in the scenarios.	Represents an independent decision dimension, keep.
Low time demand for end users	Time_dem	***	Flexibility (-0.8)	**(*)		Reason for high correlation is that alternatives which have high flexibility are decentralized ones which require more effort from users.	Keep, independent decision dimension.
Low additional area demand for end users	Area_dem	**	Drain_fail, Drain_cap (1), Illn_dir (0.9), Costs (-0.8) Forms one cluster with Drain_cap , Drain_fail, Illn_dir, Mgmt_qual	*		Correlation comes from the fact, that there are two broad categories of alternatives which have either good or bad performance depending on the objective.	Possibility for exclusion. Not very sensitive. Not that relevant.
Low unnecessary construction and road works	Road_disturb	*		*	Means for disturbance of citizens.	Decision on cooperation independent from technical system decision.	Probably not relevant in this context.
Low annual costs	Costs	****	Negatively correlated with most.	*			Keep, independent decision dimension.
Mean annual increase of costs	Cost_change	*	Illn_indir(0.8)	**		Difficult to consider without the information of total costs.	Possibility for exclusion.

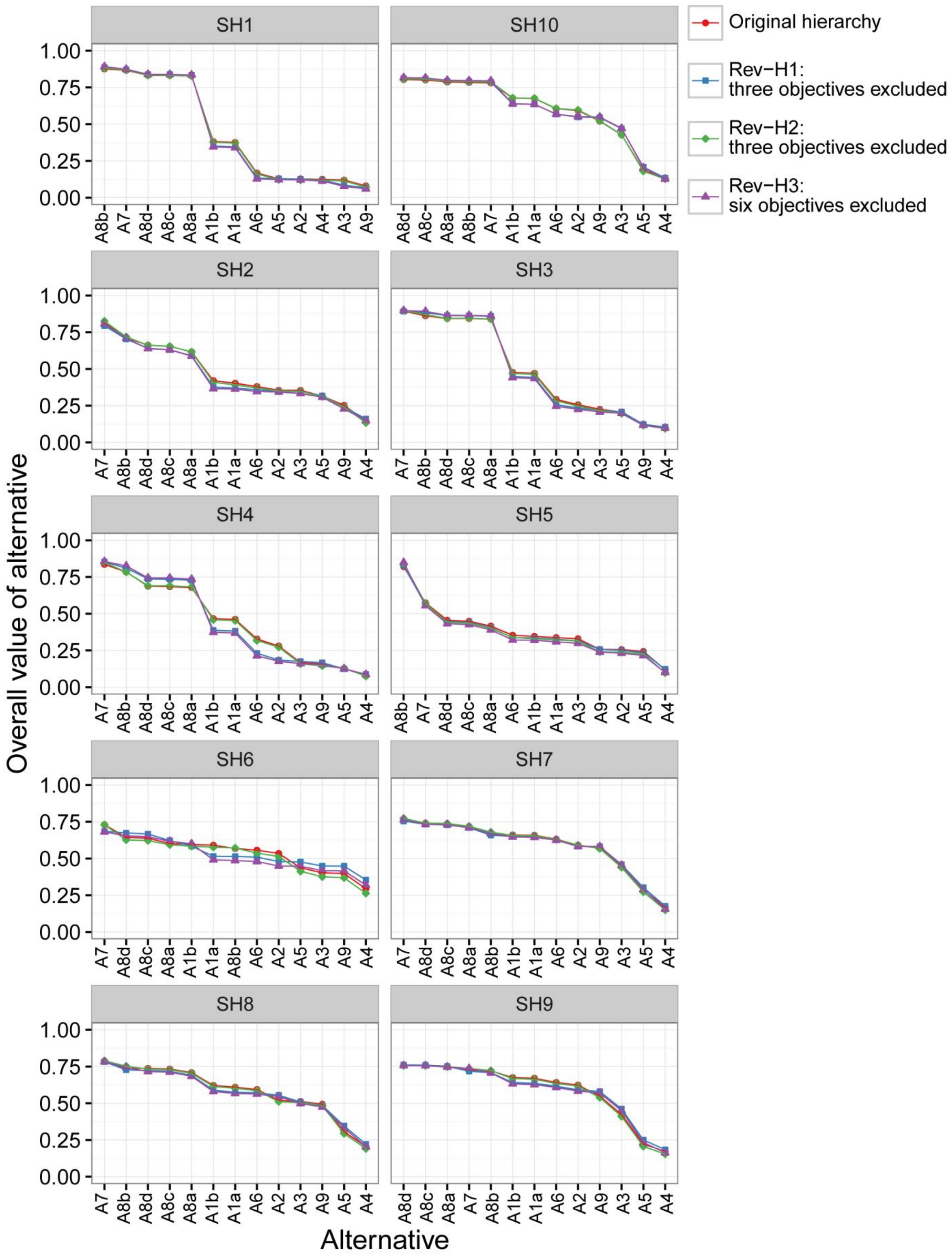
[1] Scale : Very high ****, High ***, Moderate **, Low *

[2] Only strongest correlations (≥±0.8) are indicated

[3] Scale: High ***, Moderate **, Low *

S-3-6. Impacts of the objectives hierarchy options on the overall values of alternatives of ten stakeholders in the SWIP case.

Source for the original hierarchy data Zheng et al. (2016)



S-3-7. Summary of the results of the sensitivity analysis regarding different hierarchy options in the SWIP case.

Changes in the ranking order of alternatives compared to the original hierarchy (Option 1). How many alternatives changed their ranking and what is the largest change in ranking.

	Rev_H1	Rev_H2	Rev_H3	Comments
Stakeholder 1	Five alternatives, two ranks	Four alternatives, one rank	Seven alternatives, two ranks	3rd and 4th changed orders
Stakeholder 2	Six alternatives, three ranks	Two alternatives, one rank	Six alternatives, four ranks	No changes in TOP5
Stakeholder 3	Two alternatives, one rank	Two alternatives, one rank	Four alternatives, one rank	3rd and 4th changed orders
Stakeholder 4	Four alternatives, one rank	No changes	Four alternatives, one rank	1st and 2nd changed orders
Stakeholder 5	Six alternatives, three ranks	No changes	Six alternatives, three ranks	No changes in TOP5
Stakeholder 6	Seven alternatives, three ranks	Four alternatives, three ranks	Eight alternatives, four ranks	No changes in TOP3
Stakeholder 7	No changes	No changes	No changes	No changes
Stakeholder 8	No changes	No changes	Three alternatives, two ranks	No changes in TOP5
Stakeholder 9	No changes	No changes	Two alternatives, one rank	4th and 5th changed orders
Stakeholder 10	No changes	No changes	No changes	No changes

S-3-8. Extended sensitivity analysis in the SWIP case.

In the extended sensitivity analysis, the weights of all objectives were considered uncertain. In addition to the effects of the removal of objectives also the effect of this uncertainty was studied. The description of this analysis and its results are presented below.

Preferences elicited from real-world stakeholders for the original hierarchy were used as a basis (Zheng et al. 2016), but weights were rescaled to fit attribute ranges of the chosen scenario. We assumed each elicited weight to be uncertain, with a uniform probability distribution of ±0.05 around it (average weight across all the lowest-level objectives was 0.05). To sample from the weight space, the Hit-And-Run Markov Chain Monte Carlo sampling algorithm was used, as implemented in the "hitandrun" R package (Tervonen et al. 2013). In addition to drawing from the specified probability distributions, this ensured that each weight was in the interval [0,1] and the weights summed up to one. Four stakeholders that emphasized different decision dimensions were selected. Per stakeholder 10,000 weight profiles were generated.

The overall values of nine alternatives that appeared to be most sensitive in the other sensitivity analysis (S-3-5) were calculated for each weight profile and each hierarchy option. When objectives were removed in the hierarchy options, the remaining weights were renormalised. In terms of median values, the ranking of the best alternative did not change in nine out of twelve cases (three options and four stakeholders). There are only small changes in the uncertainty of the rankings between the original hierarchy and hierarchy options. This analysis supports the notion that no large changes in the rankings produced by the SWIP MCDA model are to be expected for a range of stakeholder perspectives, even though six objectives have been removed from it.

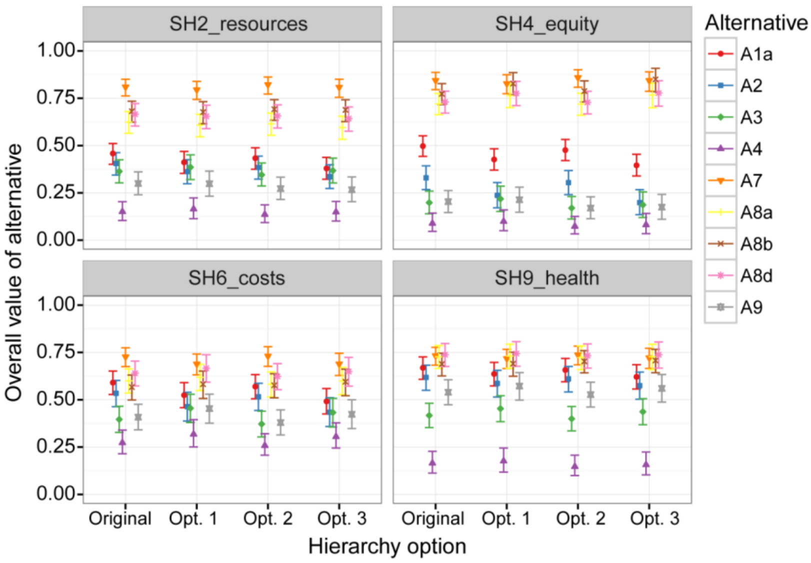


Figure 1: Overall value of different alternatives for different hierarchy options, assuming uncertainty in the stakeholder weights. The symbols give the median overall value, the error bars span the 2% and 98% quantiles, given all the weight profiles.

Tervonen, T., Van Valkenhoef, G., Baştürk, N., and Postmus, D. 2013. 'Hit-And-Run enables efficient weight generation for simulation-based multiple criteria decision analysis', *European Journal of Operational Research*, 224: 552-559.

Zheng, J., Egger, C. & Lienert, J. 2016. A scenario-based MCDA framework for wastewater infrastructure planning under uncertainty. Journal of Environmental Management, 183 895-908 doi:10.1016/j.jenvman.2016.09.027].

S-3-9. Pathway plot analysis in the SWIP case.