Water Resour Manage (2015) 29:2733–2749
DOI 10.1007/s11269-015-0967-1

Selection of the Best Inland Waterway Structure: A Multicriteria Decision Analysis Approach

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Received: 22 April 2014 / Accepted: 5 March 2015 /
Published online: 26 March 2015

Abstract This study explains the role and effectiveness of Multicriteria Decision Analysis (MCDA) approaches for decision support to rank the best option(s) to reconstruct and rehabilitate the inland waterway structure by demonstrating a case study of River Ilmenau in Germany. Considering the involvement of several stakeholders and community with the status and functionality of the Ilmenau river, this paper also considers the importance of stakeholder participation in the decision making process by an intensive stakeholder interview. A total of 27 criteria were selected that represent a wide range of environmental and socio-economic aspects of the Ilmenau River and the activities related to this river. The ranking of the alternatives were performed by combining AHP (Analytical Hierarchy Process) with PROMETHEE (Preference Ranking Organisation METHod

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for Enrichment Evaluations) to achieve a rigorous solution of the objective. 23 stakeholders such as decision-makers, experts, and researchers from environmental, administrative, recreational, and socio-economical fields were interviewed to determine the criteria to be weighed. The stakeholders' opinions showed ecological continuity is one of the most important criteria to be considered. They also gave significant importance to nature protection laws and directives. Among the socio-economic criteria, flood protection was the most important one. Removal of weirs and installation of ground ramps was suggested to be the best option to consider for further investigation and implementation. This study clearly demonstrates the importance of stakeholder and community participation to decision-making process and contributes new information, especially stakeholders' attitude towards decision making for water resources infrastructure selection.

Keywords Multicriteria analysis · Decision support · Waterway structure · Ilmenau River · Germany

1 Introduction

Multicriteria decision analysis (MCDA) provides techniques that are potentially capable of improving the transparency, conflict reduction, accountability, auditability, and analytical rigor of the decision-making process (e.g., Dunning et al. 2000) and may be applied in many different fields of science and technology. Originally, this approach was developed to choose the best alternative from a set of competing options by analyzing and quantifying the selected most representative criteria. MCDA evolved as a tool for decision-making in the 1960s and 1970s (Hajkowicz and Collins 2007; Figueira et al. 2005). Over the years, this analysis technique has received significant attention by a diverse range of disciplines, such as climate change adaptation (Giupponi 2014), energy sector (Barin et al. 2011), integrated water resources management (Geng and Wardlaw 2013), environmental management (Kiker et al. 2005) and has evolved into a wide range of decision aiding techniques. It can be applied for a whole range of ranking of alternatives and assessment of the overall impacts (Sharifi 2003). Nowadays, MCDA is an established methodology among the professionals and scientific communities in order to make use of its inherent advantages. Over time, this decision analysis technique has received particular attention in water resources management (e.g., Fontana and Morais 2013; Hajkowicz and Collins 2007; Rahman 2011). Still no MCDA application is demonstrated in the field of inland waterway.

This study's concern is the River Ilmenau, located in Germany, in the section from km 0.00 to km 17.74. The 107 km long Ilmenau River is a southern tributary of the Elbe River and is classified as a federal inland waterway. The needle weirs and locks at Bardowick (5.65 km), Wittorf (12.35 km) and Fahrenholz (17.74 km), located North of Lüneburg, regulate the water level of the river (Fig. 1). Since the needle weirs are greatly in need of repair, certain actions such as rehabilitation or demolition of the weirs or locks are required. As a number of stakeholders' activities depend on the status of the river, the executive agency "Wasser- und Schifffahrtsamt (in English, Water and

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Shipping Authority)" (WSA) Lauenburg is concerned about obtaining a possible solution of this particular problem. A detailed feasibility survey and impact assessment was performed by the executive authority in order to select the best option. However, the assessment did not reflect the importance of stakeholders and could not provide a transparent decision support. Hence, a more transparent and understandable decision support was required by the executive agency.

This paper reports for the first time, according to our knowledge, an comprehensive application of integrated MCDA approaches as a decision support for selecting best inland waterway structure by using the example of the case study of the Ilmenau River. The aim of this study is to evaluate the available options, analyse the interests of local stakeholders and independent experts, and to create decision support for the selection of the best implementable options. Strong emphasis was given to include several stakeholders in decision-making. This paper also presents a critical analysis of stakeholders' opinions and attitudes towards such a decision-making process that is very crucial in any field requiring community participation. Stakeholders' participation analysis, undertaken in this study, produces some fundamental information that is quite beneficial for the decision maker in any field of water resources management.

Fig. 1 Case study area (inset) showing the Ilmenau River (only the part of the river considered in our study)

2 Overall Methodology

In general, the entire process towards option ranking to rehabilitate or reconstruct inland waterway structures on the River Ilmenau involves three main steps: (a) options development, (b) strategy ranking: criteria selection, criteria quantification and stakeholder interview, and (c) aggregation to receive best alternative(s).

At the beginning of the study the options are formulated. During the first step, relevant hydrological, ecological, social, legal and economic criteria are selected. The next step involves the decomposition of the ultimate goal into a hierarchy of several levels. The bottom level consists of several criteria while the middle levels aggregate those into different 'criteria sub-groups'. Each criteria sub-group is related to a certain 'criteria group' that is placed one level higher in the hierarchy. All levels combined are the goal of the study, inland waterway structure selection, which is positioned at the top of the hierarchy. The next step is assigning weights for each criterion, criteria sub-group and criteria group. The final weights of each criterion, criteria sub-group and criteria group are then obtained by multiplying the specific weights of each object at given level along the path from the top of the hierarchy to the criterion itself.

For criteria hierarchy and weighting, the Analytical Hierarchy Process (AHP) (Saaty 1980) was used here. Stakeholders are interviewed to get the criteria weight. Pairwise comparison, used in this study, is a well-known procedure to acquire weighting. The criteria under each criteria sub-group are compared amongst themselves and a weight is assigned to each one. The criteria sub-groups and criteria groups are also evaluated allowing the same approach. The next step is to quantify the criteria. Afterwards, an evaluation matrix is prepared at this step and this is one of the principle components for ranking of alternatives. The final step involves aggregation, strategy comparison and ranking analysis. In this study PROMETHEE (Preference Ranking Organisation METHod for Enrichment Evaluations) (Brans et al. 1986; Brans and Mareschal 2005) was used for this purpose.

3 Description of Options

In order to maintain the ecological and hydrological conditions, and related social and economic activities, the decision makers, WSA, of the River Ilmenau formulated four options in close discussions with experts. A brief description of the options is listed below:

In Option 0 (V0), the weirs and sluices would essentially be rebuilt. The locks in Wittorf and Fahrenholz would be completely replaced, but they would be repaired in Bardowick. As the condition of dams no longer ensures occupational safety, they would be rebuilt according to state-of-the art technology. This is taken as first option in this study. To improve the ecological continuity, a fish passageway would also be built at each weir. Another option, called Option 1 (V1), had been formulated but was eventually not considered any more as a feasible option (NLWKN 2012). This option is not included in this present study.

The second option (V2) provides a complete dismantling of the needle weirs including the ground swelling. At the same time the locks would be converted into a gutter, i.e., gates, supply and disposal lines and expendable solid components are removed. Since no more storage elements are present, the water level can drop significantly in summer. At the same time, ecological continuity is ensured. Option 3 (V3) is characterized by the incorporation of ground ramps (slope is about 1:50) on the channels. Simultaneously, the weirs are to be completely dismantled as in V2. This could facilitate storage about half of the mean discharge, while ensuring further ecological continuity. The option 4 (V4) corresponds to the assumptions of option 0 without replacement construction of the sluices, but their dismantling. The water levels also correspond to the current state, so the associated conditions do not change. The difference to the V0 is the reduced passage for water vessels that cannot be navigated due to the limited water level.

4 Criteria Selection, Weighting and Quantification Procedure

4.1 Criteria Selection

A wide range of factors was considered for the selection of criteria. The criteria were derived from the identified sectors of impact and consideration was given to the availability of information to quantify the criteria. The 27 most representative decision criteria were selected in close cooperation with decision makers and were discussed with other experts in related fields. Table 1 shows the list of criteria with a brief explanation.

4.2 Criteria Hierarchy

Figure 2 shows the four-level hierarchical structure considering all criteria. This is considered as the first step of multcriteria decision support.

27 criteria (at ‘Level 3’) were grouped into seven criteria sub-groups such as nature protection, hydrology, ecology, cost, operation & maintenance, tourism & recreation, and social convenience. At the level 1 of the hierarchy, nature protection, hydrology and ecology sub-group were grouped as ‘Environment’ and cost, operation & maintenance, tourism & recreation and social convenience sub-group were grouped as ‘Socio-economy’.

4.3 Criteria Weighting

Stakeholders’ involvement and community participation were ensured at this stage in order to achieve a transparent decision-making process. The relative importance of each criterion was defined in close cooperation with local scientists, decision makers and other stakeholders. A participative process was undertaken. The participative process includes (a) scientific meeting(s), (b) questionnaire survey(s), and personal interview(s). In total 23 relevant stakeholders were interviewed who are concerned with the status of Ilmenau River.

According to the interest and responsibility of the stakeholders, six interest groups were formed. In order to obtain the weighting from each stakeholder, a pairwise comparison matrix was prepared. Together with the pairwise comparison matrix, a detailed description of the criteria was supplied to the stakeholders (Table 1). The interviews were conducted by personal visits, telephone and via email communication. In some cases, two or three persons from one stakeholder institution were interviewed and the average of these interviews was considered for further analysis. The consistency of stakeholder’s preferences was checked according to the equation described in Saaty and Vergas (1991). In case of inconsistency, the corresponding stakeholders were requested to reassign the importance for that particular comparison matrix.

4.4 Criteria Quantification Procedures

The relevant criteria were quantified using state-of-the art technologies. A feasibility study was carried out by the executing agency, WSA, together with the Lower Saxony state office of water management, coast and nature protection (NLWKN, Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz) to assess and to evaluate the relevant criteria.

Table 1 Table listing the criteria with brief explanation

Criteria No.	Criteria name	Brief description
C1	Compliance with FFH guidelines	Represents the law in EU directive from 1992 to protect certain animals, plant species and habitat type. "FFH" stands for flora, fauna, habitats. The Directive aims to ensure the protection of European wildlife and plants and their habitats
C2	Compliance with FFH BnatSchg and NAGBNatSchG guidelines	Represents the Federal and Lower Saxony laws (related to FFH BnatSchg) to protect certain biotopes that have influence on nature and ecology. The law confirms the protection of certain habitats according to § 30 of the Federal Nature Conservation Act and § 22 and § 24 of the Organic Law of Lower Saxony of the Federal Nature Protection Act (related to NAGBNatSchG). Impairment of the habitats listed are indeed illegal, but can be allowed for overriding public interest
C3	Sedimentation & erosion	Sedimentation and erosion would affect the self-cleaning potential of the river. The less sedimentation and erosion, the more effective natural flow in the river
C4	Water level	Measures the water level in the river. A certain water level should be maintained to secure navigation
C5	Soil properties & drainage	Represents the soil properties such as its ability to hold water and drain water. These soil properties are important for the agricultural sector near the river
C6	Natural flowing water development	Used to stress the importance of natural flow conditions of the River Ilmenau
C7	Ecological continuity	Ensures the fish movement within the river without obstacles. This is one of the most important parameters mentioned in the European Water framework directive
C8	Air circulation near soil	Measures the natural condition of the soil and its surroundings, such as the presence of woody plants to filter the air and microclimatic influences on habitats, etc.
C9	Water quality: Biological component	Measures the relative change of water quality (biological components such as Phytoplankton, macrophytes, Phytobenthos, benthic invertebrates, fish fauna etc.) due to the option implementation. The biological components are considered to follow the European water framework directives (WFD)
C10	Water quality: Other component	Measures the relative change of water quality (other than biological components such as pH, water temperature, salt content, etc.) due to the option implementation. The water quality components are considered to follow the European Water Framework Directives (WFD)
C11	Investment cost	Measures the present value of the net investment costs. It indicates whether the project should be accepted or rejected on economical terms considering direct costs
C12	Operation cost	Represents the present value of the net operation costs to functioning and maintaining the waterway structures
C13	Other costs due to legal requirements	Considers others costs such cost for mitigation and compensation measures
C14	Operation security	Considers the operational security of the water way structures
C15	Work safety	Measures the security of the personnel while operating the weirs, locks, and dams
C16	Protection of other buildings	

Table 1 (continued)

Criteria No.	Criteria name	Brief description
		Considers the protection of other structures and buildings that can be damaged due to the unnatural condition of the river
C17	Navigation	Considers the navigation facility and opportunity in the River Ilmenau.
C18	Farming	Measures the farming related activities (e.g., water supply for agriculture) that are dependent on the water of Ilmenau River
C19	Tourism	Considers aspects related to tourism such as attractiveness of the Ilmenau region, recreational opportunities, etc.
C20	Cycle touring	Opportunity and attractiveness of cycle touring along the Ilmenau is represented by this criterion
C21	Water sports	Considers the opportunity and attractiveness of water sports along the Ilmenau, eg canoeing
C22	Fishing	Ensures the representation of the possibility of private and commercial fishing on the river Ilmenau in the analysis
C23	Acceptance	General acceptance of local residents regarding the rehabilitation or renovation of the weir/sluice installations and the resulting changes to the social life
C24	Recuperation	Measures the recuperation potential of the River Ilmenau
C25	Landscape	Represents the preservation or improvement of the existing landscape by implementing the renovation action
C26	Historical heritage conservation	Considers the value of the existing waterway structures from the heritage point of view. The old structures might be considered as heritage site
C27	Flood protection	Indicates the importance of flood protection to the community. The Ilmenau is a designated flood zone, so appropriate measures are required

Groundwater modelling, economic analysis, environmental impact assessment, and a questionnaire survey were performed to evaluate each criterion against each option. In this study, the quantified values were taken from the feasibility study (NLWKN 2012). The feasibility study

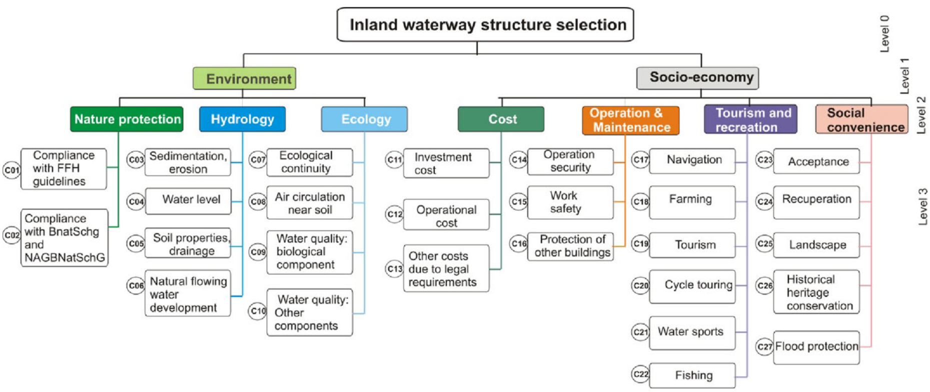


Fig. 2 Hierarchical structure of the criteria

prepared the evaluation by assigning symbols (e.g., ++, +, 0, −, −-). We transformed each symbolic evaluation score to a numerical value by using the following transformation criteria:

- - (unsuitable)=1; − (partially suitable)=2; 0 (suitable with restriction)=3; + (suitable)= 4; ++ (very suitable)=5;

After quantification of all the criteria, a normalized evaluation matrix was prepared.

4.5 Criteria Aggregation and Ranking of Options

A number of MCDA methods have been proposed, developed and applied in different fields of science and technology including water resources management, e.g., AHP (Saaty 1980), WLC (Eastman, et al. 1993), PROMETHEE (Brans et al. 1986; Brans and Mareschal 2005) ELEC TRE (Roy and Bouyssou 1993), SMART (Edwards 1977), Goal Programming (Charnes and Cooper 1961). As recommended by Macharis et al. (Macharis et al. 2004), we applied both AHP and PROMETHEE. Through this, we can make use of the advantages of AHP regarding criteria structuring and weighting as well as of PROMETHEE with respect to transparent and user-friendly data aggregation. PROMETHEE do not provide any formal guidelines to obtain criteria weights. In fact, PROMETHEE does pairwise comparison while aggregating the evaluation matrix to rank the option. PROMETHEE method considers positive and negative out-ranking flows offering detailed information on the ranking of alternatives. Thus, it avoids the trade-off among the criteria. Weighted linear combination method (WLC) is a simple method and considers trade-off among the criteria, alike AHP. Trade-off might cause loss of information. PROMETHEE is better suited for sensitivity analysis compared to AHP method.

4.6 Brief Description of MCDA Methods

The detailed description of AHP (Saaty 1980) and PROMETHEE (Brans et al. 1986; Brans and Mareschal 2005) can be found in the literatures and hence the methods are not explained in details.

4.6.1 Analytical Hierarchy Process (AHP)

The AHP, proposed by Saaty (1980), can be considered as a structured methodology for analyzing and solving complex decision problems by structuring them into a hierarchical framework. It combines qualitative and quantitative approaches. This procedure is important for decision problems with a large number of criteria (Eastman et al. 1993). Developing the hierarchical structure, obtaining preference information, estimation of relative weight by pairwise comparison and construction of overall priority ranking are the main steps of AHP.

The pairwise comparison method, originally proposed by Saaty (1980), is used to transfer the linguistic importance to numeric value and relative weights were estimated.

Stakeholders' (including decision-makers) preferences might be inconsistent while assigning importance to each comparison and this inconsistency was checked by the formula proposed by Saaty and Vargas (1991). According to them, CR should be <0.1; although CR$<$ 0.2 is considered tolerable (Wedley 1993). In this study, the average of this range, 0.15, was considered to be the threshold. It indicates that if any pairwise comparison matrix gives CI value greater than 0.15, this matrix will be considered as inconsistent.

The pairwise comparison procedures have been described in many articles (e.g., Saaty 2001) and therefore is not explained in this paper. However, it should be mentioned that there is also criticism on using AHP (e.g., Stewart 1992; Belton and Gear 1983). One example is: there are considerable discrepancies to axiomatic foundation of utility theory. Therefore, it is doubted whether the alternatives in AHP could actually be assessed based on an additive value function.

4.6.2 Preference Ranking Organisation Method for Enrichment Evaluations (PROMETHEE)

PROMETHEE, developed by Brans (1982), is a non-parametric outranking method for a finite set of alternatives. The method was later extended by Brans and Vincke (1985), and Brans and Mareschal (1994). PROMETHEE I derives a partial ranking which allows incomparability and PROMETHEE II provides a complete ranking of the strategies by using the net flow (Brans 1982, Brans and Mareschal 1994). After receiving the criteria weights and preparing an evaluation matrix, attribute-specific preference functions needs to be defined to set up a PROMETHE II analysis. The procedures are explained in several literatures (e.g., Brans, 1982, Figueira et al. 2005).

According to PROMETHEE-GAIA (2012), the type I and type IV preference functions are best suited for qualitative criteria while the type III and type V preference functions are best suited for quantitative criteria. The Type II preference function is a special case generated from Type I and is seldom used. On the other hand, the type VI preference function is less often used due to its difficulty to set the parameters correctly (PROMETHEE-GAIA 2012).

The different preference function against each criteria was discussed with the decision maker. Because the criteria values are between 0 and 1, Type III preference function was chosen for each criterion.

Basically, the entire MCDA approach is a combination of components of AHP with PROMETHEE. After preparing the hierarchy of criteria, the role of AHP was the estimation of relative weights after getting pairwise comparison matrices the decision makers and stakeholders. The role of PROMETHEE was to aggregate the information and prioritize the options. PROMETHEE was also used to do sensitivity analysis.

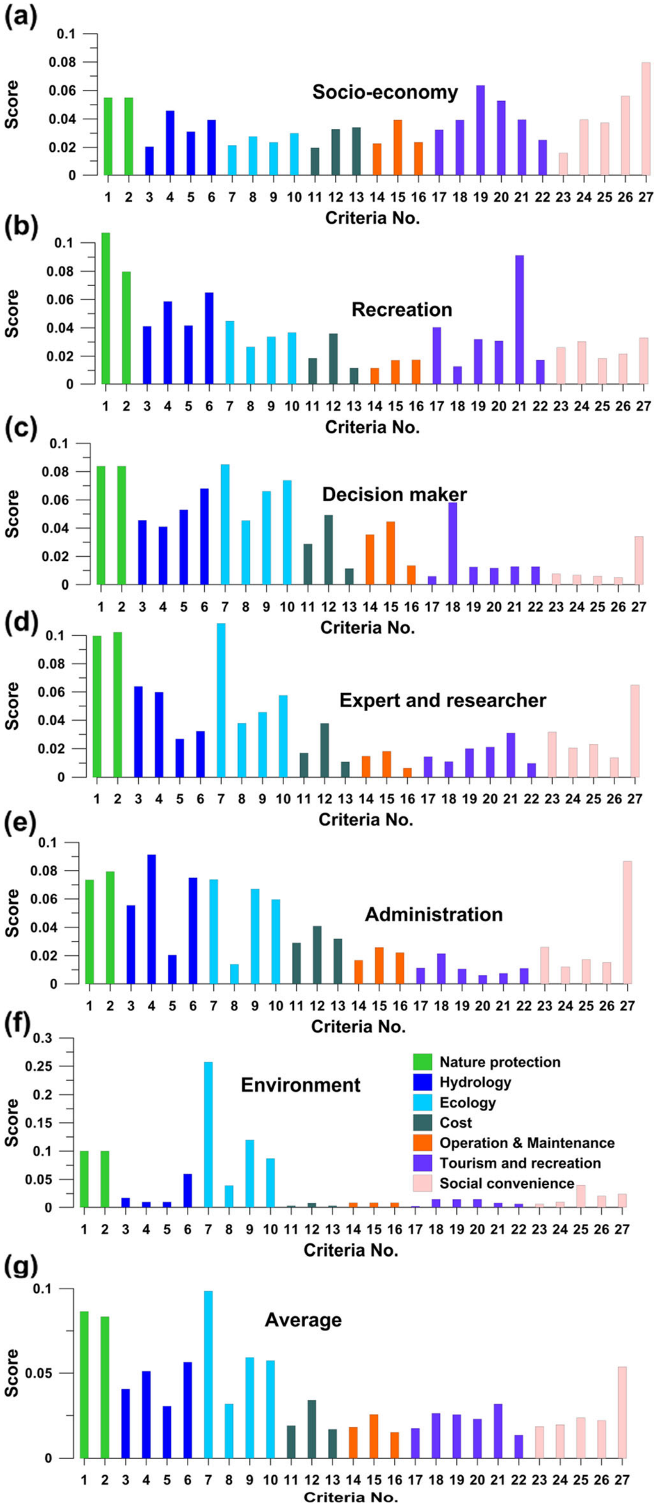
4.7 GAIA Plane

It is recommended within PROMETHEE to visualize the option ranking and to identify individual influences of the criteria on the GAIA (Geometrical Analysis for Interactive Assistance) plane (Brans and Mareschal 2005). GAIA plane is based on the principal component analysis (PCA) technique, which allows converting the multidimensional space into two dimensions. Through the information of the GAIA-plane, it is possible to identify which criterion is supportive of which options and how important the criterion is for the decision problem as a whole. Furthermore, the GAIA-plane shows the interaction of the criteria, depicting both the dependence and interdependence among them.

4.8 Sensitivity Analysis

The sensitivity analysis (SA) should be conducted where uncertainty exists in the construction of hierarchy, selecting MCDA approach and in the assignment of relative importance (Store and Kangas 2001). In this study, a non-probabilistic SA (Feick and Hall 2004) was used to investigate criteria weight uncertainty, as these criteria are often subjectively defined.

With respect to PROMETHEE, the use of an insensitivity interval is recommended for a sensitivity analysis (Mareschal 1988; Geldermann et al. 2000). Such an insensitivity interval describes the scope at which an original chosen criteria weight can be adjusted without changing the ranking of the options.


(a)
Socio-economy
Score
Criteria No.
(b)
Recreation
Score
Criteria No.
(c)
Decision maker
Score
Criteria No.
(d)
Expert and researcher
Score
Criteria No.
(e)
Administration
Score
Criteria No.
(f)
Environment
Nature protection
Hydrology
Ecology
Cost
Operation & Maintenance
Tourism and recreation
Social convenience
Score
Criteria No.
(g)
Average
Score
Criteria No.

◀ **Fig. 3** Weighting of the criteria according to (**a** to **f**) the stakeholder group, (**g**) Averaged weights of the criteria (equal weighting of every stakeholder)

5 Results and Discussion

5.1 Stakeholders' Importance to the Options

Figures 3a to g present the normalized score of the stakeholders' importance to the criteria. The socio-economy group gave the highest importance to tourism and flood protection (Fig. 3a). Cycle touring and nature protection were also weighted highly. The major importance, in general, was given to the socio-economy criteria group. Little variability was observed in the distribution of criteria importance by this group. On the contrary, high variability was observed in the importance distribution by the recreation group (Fig. 3b). This group was mostly concerned with protection of nature and water sports, which does match with the basic characteristics of this group. The decision-maker stakeholder group showed their importance and interest to the environment criteria group (Fig. 3c). Ecological continuity was considered as the most important criterion followed by nature protection. This group expressed little importance to the socio-economy criteria group. The expert and research group showed this similar trend in criteria importance (Fig. 3d). The variability of the scores among the criteria is higher with this group in compared to the decision-maker group. High variability in weighting was also shown by the administration group (Fig. 3e). To this group, flood protection is the most important followed by water level and nature protection, respectively. A significant importance of the 'environment' group went to the ecological continuity (Fig. 3f). They showed, in general, very little importance to the socio-economy criteria group. However, the average of all the importance scores (Fig. 3g) shows that the ecological continuity is the most important followed by nature protection, flood protection, and biological and other water quality components, respectively. The variability of the importance among the criteria is high. Basically, the average of all weights shows much importance to the environment criteria group, which is prominent to the weighting done by each stakeholder group, except socio-economy group.

It is clear from the analysis that some stakeholders group (such as socio-economy) have different preference, expressed in terms of criteria weighting, than that of decision maker, indicating the need of including the stakeholders in decision making. In this study, the decision-makers carefully and positively considered the preferences of the stakeholders for further operation and maintenance of the waterway.

Figure 4 shows the dispersion of the weight for each criterion among the 23 stakeholders. It is clear that ecological continuity, compliance with FFH guideline, water sports, and flood

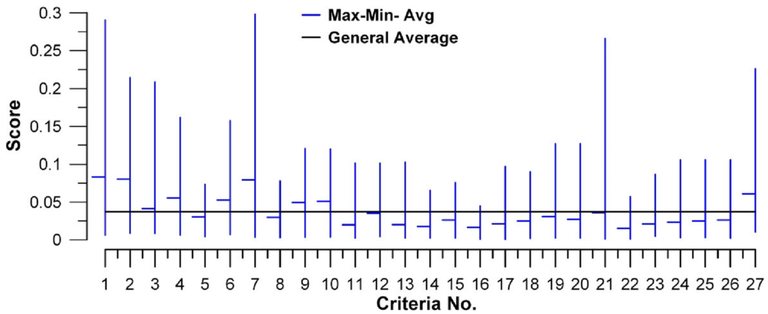


Fig. 4 Dispersion of the criteria weighting

protection criterion are critical, considering dispersion in weights. Therefore, their influence on the project should be analyzed carefully. Protection of other buildings, fishing, and soil properties are similarly important to the stakeholders.

The results of the consistency analysis (CI is 0.15) of the weights show that the stakeholders are remarkably efficient assigning relative weight in the pairwise comparison. Only 14 out of 200 pairwise comparison matrices were not consistent. The inconsistency was carefully handled in this study. Finally, the weights were mainly consistent and therefore these values were used directly for aggregation and ranking.

5.2 Lessons Learned: Stakeholders Attitude Towards the Decision Making Process

During the stakeholders' interview, we had gathered a number of issues that are quite interesting and important for any kind of decision-making. A self-explanatory list, Table 2, gives a brief description of the key issues and the stakeholders' attitude towards them.

5.3 Evaluation Matrix

It is clear from the evaluation matrix that the V0 has better performance considering the socio-economy criteria group over the environment criteria group. No criterion from the socio-economy group has a '0' score. In V0, among the 27 criteria, only two criteria: compliance with BNatSchG (Federal Nature Conservation) and NAGBNarAchG (Organic Law of Lower Saxony of the Federal Nature Protection Act), and investment cost show worst performance (score 0) and 10 criteria show the best performance (score 1). V2 shows best performance in ecological criteria. In V2, −seven criteria show worst performance and 5 criteria show the best performance.

V3 shows comparatively better performance considering the environment criteria group over the socio-economy criteria group. This performance is opposite to V0. In V3 only three criteria show worst performance and only 4 criteria show the best performance (score 1). No criterion from the environmental group has a score '0'. V4 has good distribution of performance among the criteria of both the environment and the socio-economy group. In V4, only 3 criteria show worst performance and only 7 criteria show the best performance. Air circulation near soil performs the best (score 1) in all options that is followed by performance reliability and work security criterion. Law and investment cost perform the worst (score 0) in two options. In general, according to the average of the normalised score, V0 performs the best (avg. value is 0.73). The average normalised values of V4 (avg. value is 0.66) and V3 (avg. value is 0.64) are very close. V2 (avg. value is 0.47) can be considered inferior to the other three options, in terms of evaluated values. This is not the real ranking. The weight assigned to each criterion by the stakeholders would play an important role during aggregation and ranking of the options. This is the essence of MCDA approach.

5.4 Aggregation and Ranking Analysis

Concerning the average weights of all stakeholders, a partial pre-order corresponding to PROMETHEE I has been obtained. It shows that V0 and V3 are incomparable to each other, but perform better than V2 and V4, which are also incomparable among each other.

Figure 5 shows the ranking of options using combined AHP and PROMETHEE II analysis techniques (using net out-ranking flow values). On the one hand, the ranking is given for all interest groups individually (Fig. 5a) and on the other hand, an average of their weighting was applied by using the weightings from all stakeholders (Fig. 5b).

Table 2 Stakeholders' attitude to the MCDA process

Key issue	Stakeholders' attitude
Involvement in the decision making process	Most of the stakeholders were happy to become an integral part of the decision making process and appreciated the idea of interview process. They mentioned that it must be considered at every sector (such as implementation of development work in energy sector, infrastructure development etc.).
Participation	As mentioned, out of 28 stakeholders, 23 stakeholders, including those who have major interests and involvement to the River Ilmenau, did participate in the interview process.
Conversation	The conversation with the stakeholders was very nice and friendly showing their real attitude and respect towards the decision-making process.
Engagement	During the interviews, the majority of the stakeholders showed profound engagement to the entire process and responded to the questionnaire survey. This true engagement reflects the consistency of weighting while doing pairwise comparisons.
Conflict	The list of criteria was the main critical point for detailed discussion. Some stakeholders wanted to include some other criteria that seemed important from their point of view. We rechecked their suggestions. Some stakeholders opined to include a numerical value in AHP pairwise comparison (Table 4) when the concerned criterion was not their own particular interest and had no idea about it. Therefore, they were not willing to give any value against their other concerned criteria.
Emotion	This study found that some stakeholders involved emotionally to the decision-making process. Some stakeholders have been negatively-biased by events that happened before the survey. They felt disadvantaged by the decision-makers and applied these negative feelings to the MCDA process. According to the definition given by Luoma-aho (2010), this study also recognises two extremes of emotional stakeholders: Faith-holders (positive emotional) and Hateholders (negative emotion). The 'Hateholders' were also anxious that their opinion might be neglected in the decision making process. The decision makers are well informed (but not the name of the particular stakeholder) about this issue.
Communication media	The success of a MCDA study depends not only communicating with the stakeholder but also the media of communication. In our study we used three media: (1) email, (2) telephone; (3) personal visit. We found personal visit to be the most effective way to handle the heterogeneous stakeholders emotions, potential conflicts and to confirm their enthusiastic involvement.
Consistency in criteria weighting	Email and telephone communication seemed less effective to get consistent relative weights while performing pairwise comparison. Personal interview procedure was found to be effective to get consistency in weighting.
Easiness of approach	The approach of assigning the weights was quite easy for the stakeholders and they could manage to perform the pairwise comparison with high accuracy.

The average of the entire stakeholder ranking scores produce, by PROMETHEE method, the following ranks:

V3: Rank 1, V0: Rank 2, V4: Rank 3, V2: Rank 4

From the average of all criteria evaluation and priorities by the stakeholders, the best option is Option V3, which is followed by V0 and V4, respectively. Option V2 holds the lowest position.

It is interesting to observe that according to the average normalized evaluation value (section 6.3), the ranking is V0<V3=V4>V2, but after including stakeholders weight and aggregating with the averaged normalized evaluated value, the ranking is different. This confirms that stakeholders' weights attached to each criterion have large impacts on the final

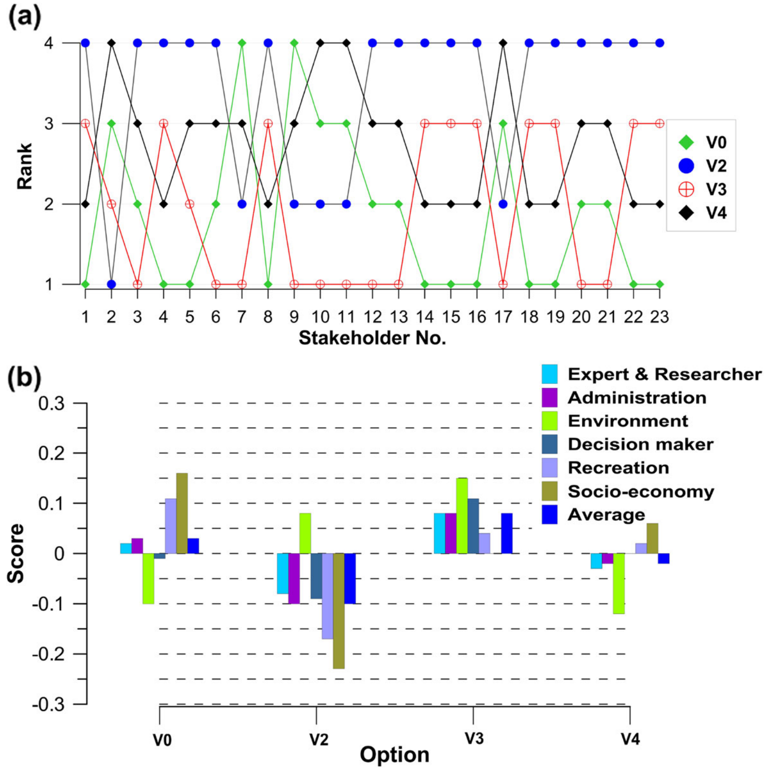


Fig. 5 **a** Ranking of the options by the individual stakeholder; **b** Ranking of the options

analysis and outcomes. This also proves the convoluted nature of the decision-making and demonstrates the applicability, potentiality and effectiveness of MCDA approaches for solving these non-straight forward decision making problems in the field of water resources infrastructure planning and management.

5.5 GAIA Plane

On the basis the GAIA-plane, it becomes apparent that there are many criteria which are supporting V2 and V4, but these options have contrary impacts. This is shown through the body of criteria, which are supporting these options, but pointing in contrary directions. In the visualization (Fig. 6) of the GAIA-plane, it can be seen that the projections on the decision axis of the three alternative V0, V3 and V4 are very close together. This is in accordance to the net-flows, which are quite similar. It is conceivable, that V0 and V3 perform well because these alternatives represent good trade-offs.

5.6 Sensitivity Analysis

A sensitivity analysis, expressed as the stability of weighting points out that for a number of the criteria a change in the weights will not have any impact on the overall ranking. However, there are also some criteria such as navigation, tourism, and acceptance (the weight ranges between 0.017 and 0.05), for which a small change in the weight would result in a new

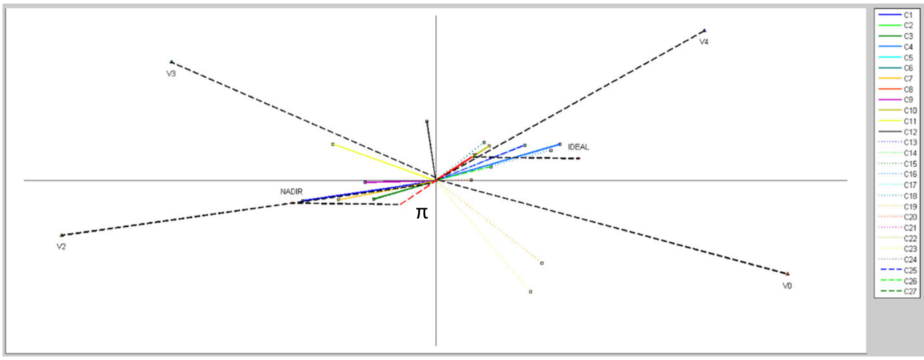


Fig. 6 PROMETHEE - GAIA-plane for the stakeholders (average weighting)

ranking. Therefore, it is strongly recommended to have an intensive investigation on those criteria and the chosen weights, especially because it represents an average at this step.

6 Conclusions and Recommendations

In this study, a MCDA approach was used to support the decision-maker to select the best option for the reconstruction and rehabilitation of the waterway structures in the River Ilmenau, Germany. In particular, a closer look was taken on the individual preferences of the different stakeholder groups.

The stakeholders participated in the interviews with a lot of enthusiasm and were very consistent while giving the weighting for the criteria. Some negative emotions from the stakeholders were identified and the decision-makers need to improve the situation to maintain a good decision-making environment. On the basis of dispersion of weighting four criteria such as ecological continuity, compliance with FFH guidelines, water sports, and flood protection; and on the basis of sensitivity analysis three criteria such as navigation, tourism and acceptance are figured out as vital and need special consideration before implementation of any structural measures.

The MCDA approaches, considering the average of all stakeholders' group weights, suggest that V3 (removal of weirs and installation of ground ramps) would be the best option to consider for further investigation and implementation. Both integrated approaches show similar rankings and hence, proves the robustness of the entire MCDA approach used in this study. The stability of weights can be a fruitful support to analyse the uncertainty in stakeholders' opinions.) The results show the range of applicability of MCDA approach in decision support for waterway structure selection, The diverse dimensions of the decision criteria and their scales of sensitivity can be taken into account for future project planning,

It is recommendable to establish close interaction between the MCDA study team and the feasibility study team to maintain a good flow and interaction of information. According to the stakeholders' opinion analysis, the stakeholders' involvement might be considered with two phase of any MCDA study: (a) at the preliminary phase while developing the options and screening the criteria, and (b) later assigning criteria importance. However, the experience from the study was that personal communication with the stakeholders improved the quality and correctness of the study, and hence, several group discussions can be done if a number of stakeholders' are involved.

Acknowledgments The authors gratefully acknowledge the contribution of Wasser- und Schifffahrtsamt (WSA) Lauenburg, Germany for funding the study. Special thanks to Ms. Couzens for her enthusiastic cooperation during the study (August 2012- November 2012).

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