Multicriteria Decision Making Model for HPP Alternative Selection

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Abstract. The development and implementation of new hydropower plant projects as a way of increasing the share of electricity generation from renewable energy sources is an imperative for the energy sector. Electricity that will be produced in new hydro power plants should be the basis for sustainable development, which is conditioned by the balance between economic, technical, social and environmental demands. Therefore, in addressing the problem of making choice on technical solution variants for hydropower plant, these requirements should be considered. Since the choice of optimal variants is influenced by various factors (criteria), mostly conflicting with each other, this problem is a matter of multicriteria decision making (MCDM). This paper presents a model for multictiteria decision making on technical solution for hydro power plant from the Pareto set of alternatives. An analytic hierarchical process was applied, taking into account quantitative and qualitative criteria. The model was tested on a specific example.

Keywords: Sustainable development · Hydropower plant · Multicriteria decision making · Analytic hierarchy process · Economic · Technical Social and environmental criteria

1 Introduction

The terms such as sustainability, energy and multicriteria decision making are terms which are very often used together in papers on energy projects and sustainability [1–8]. The main objective of this paper is to develop a model for the evaluation and selection of solutions from the Pareto set of solutions (alternatives for HPP schemes) using the Analytic Hierarchy Process method [9]. The model should also include the economic, technical, social and environmental criteria (quantitative and qualitative) which are immanent to the real problems of decision making on the HPP scheme, when a decision maker is unable to accurately determine the value of individual criteria or when they are hardly measurable.

M. Hadžikadić and S. Avdaković (eds.), *Advanced Technologies, Systems, and Applications II*, Lecture Notes in Networks and Systems 28,
https://doi.org/10.1007/978-3-319-71321-2_14

The development of the model is implemented through a series of steps:

1. Selection of decision making criteria,
2. Selection of methods for multicriteria decision aid,
3. Structuring of the decision making hierarchy,
4. Application of the Analytic Hierarchy Process method,
5. Testing of the model.

2 Decision Criteria

The criteria are selected in accordance with the tree dimensional view of sustainability (economic, environmental and social) and they are immanent to real problems of decision making on the HPP technical solution alternatives. It is possible to evaluate the extent to which a certain alternative contributes to achieving the objective of sustainable development referred to each other and to compare alternatives on the criteria basis (attributes of alternatives). Analogous to the tree dimensional view of sustainability, the criteria are also divided into 3 groups of criteria:

- economic and technical criteria (5 criteria given in Table 1).
- environmental criteria (6 criteria given in Table 2).
- social criteria (7 criteria given in Table 3).

Table 1. Economic and technical criteria

Criteria	Designation	Unit of measure	Max/Min
Installed capacity	EC1	[MW]	Max
Energy generation	EC2	[GWh/a]	Max
Investment costs	EC3	[Mio EUR]	Min
Specific costs	EC4	[EUR/kWh]	Min
Flexibility in generation	EC5	qualitative	Max

Table 2. Environmental criteria

Criteria	Designation	Unit of measure	Max/Min
Aquatic life	ENC1	Linguistic value	Min
Fauna/Flora	ENC2	Linguistic value	Min
Water quality/sediments	ENC3	Linguistic value	Min
Air quality and micro climate	ENC4	Linguistic value	Min
Noise and vibration	ENC5	Linguistic value	Min
Climate change	ENC6	Linguistic value	Min

Table 3. Social criteria

Criteria	Designation	Unit of measure	Max/Min
Resettlement	SC1	Linguistic value	Min
Loss of land	SC2	Linguistic value	Min
Cultural heritage	SC3	Linguistic value	Min
Traffic and infrastructure	SC4	Linguistic value	Min
Labour and employment	SC7	Linguistic value	Max
Landscape	SC8	Linguistic value	Min
Community acceptance	SC9	Linguistic value	Max

3 Selection of Multicriteria Decision Making Method

Due to the complexity of the decision making problem and large interdependence of the selected criteria, as well as due to number and nature of the criteria imposed by the need to rely on the assessment, Analytic Hierarchy Process is selected and applied as a multicriteria decision making method, which, in its essence is the most appropriate for the problem and the context of decision making. The basic concept of applied Analytic Hierarchy Process method is hierarchical structure of decision making, pairwise comparison and the bottom up synthesis of priorities through the hierarchy. The key advantage compared to the other MCDM methods is that with the Analytic Hierarchy Process, decision makers are not required to accurately determine the value of individual criteria (when they are hardly measurable or when there is no available data).

4 Hierarchy of Decision Making and Model Parameters

The problem of decision making is structured in a hierarchy that has 4 hierarchical levels:

1. Objective: selection of the best alternative from the Pareto set of HPP alternatives
2. Criteria groups
3. Criteria (listed in the criteria groups)
4. Alternatives (Pareto set of alternatives).

The number of alternatives is a variable in the model and the specific parameters of the model are:

1. Number of levels in a hierarchical structure (3),
2. Number of criteria groups (3),
3. Total number of criteria (18),
4. Number of economic and technical criteria (5),
5. Number of environmental aspect criteria (6),
6. Number of social aspect criteria (7).

5 Input/Output

Inputs for the model are expert assessments of criteria importance and priorities of alternatives that are entered into pairwise comparison matrices:

1. Pairwise comparison matrix of criteria groups with respect to the objective
2. Pairwise comparison matrix of economic and technical criteria with respect to the corresponding group
3. Pairwise comparison matrix of environmental criteria with respect to the corresponding group
4. Pairwise comparison matrix of social criteria with respect to the corresponding group
5. Pairwise comparison matrices of alternatives with respect to each of the criterion.

The output of the model are priority values for alternatives sorted from largest to smallest. The best alternative has the highest value of priority.

6 Consistency Check

Pairwise comparison matrices are positive, squared and reciprocal. Elements of matrices are numbers from Saaty's scale and consistency check is made according [9]. The scale is shown in Table 4.

Table 4. Saaty's scale

Definition	Importance intensity	Reciprocals
Equal importance	1	1
Moderate importance	3	1/3
Strong importance	5	1/5
Very strong importance	7	1/7
Extreme importance	9	1/9
Intermediate values	2, 4, 6, and 8	1/2, 1/4, 1/6, and 1/8

7 Algorithm Model

The model can be realized through the algorithm whose flowchart is presented in Fig. 1.

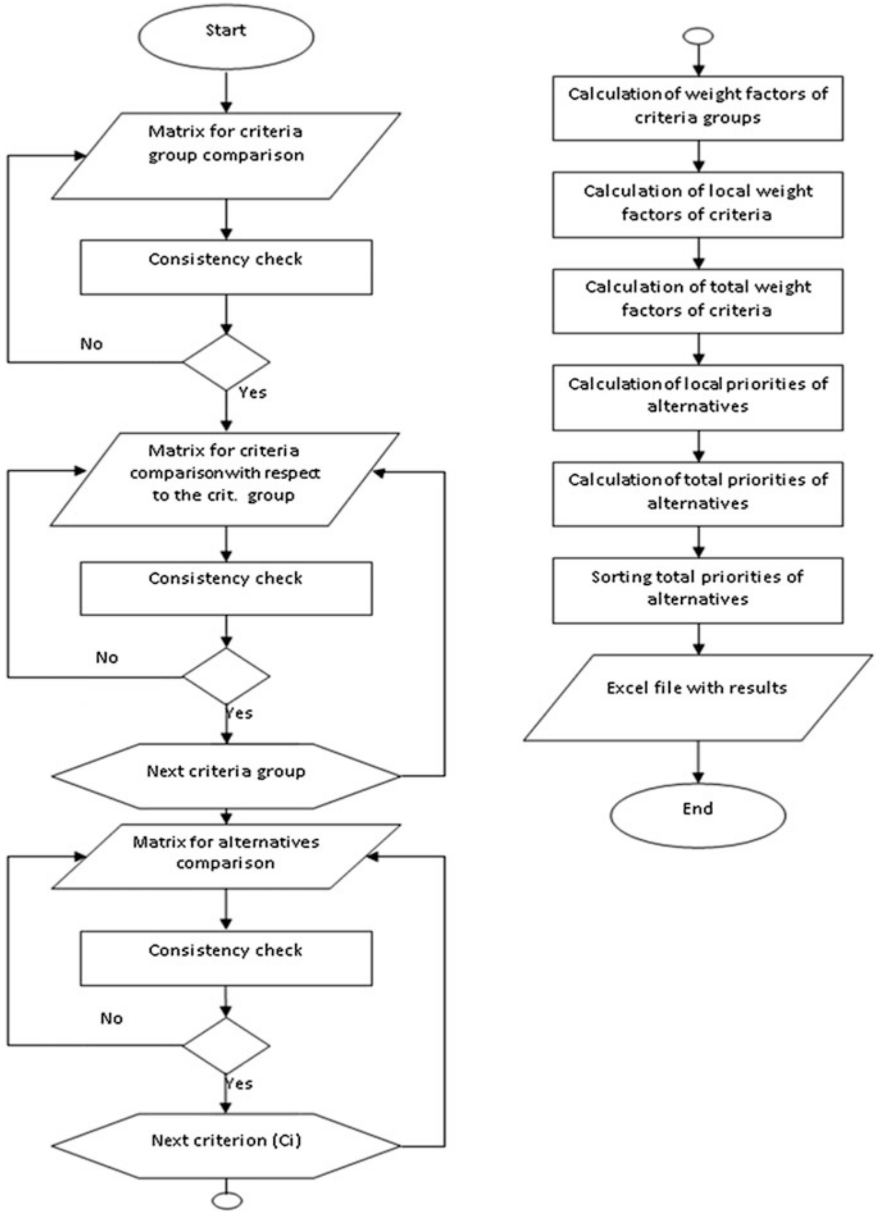

Fig. 1. Flowchart of algorithm model

8 Testing Model on a Concrete Example

The developed model is tested on a concrete example of the selection problem for the best alternative of 5 HPP scheme alternatives, using a Java application made on the basis of the algorithm of the developed model. The alternatives are given in the Table 5. The evaluation scale for qualitative criteria (attributes) is given in the Table 6.

Table 5. The alternatives

Economic and technical criteria				Alternatives				
				A1	A2	A3	A4	A5
1.	Installed capacity	Quantitative	MW	5.12	6.45	6.35	10.45	10.18
2.	Energy generation	Quantitative	GWh/a	26.04	33.94	32.30	56.27	53.81
3.	Investment costs	Quantitative	Mio EUR	35.5	41.9	41.2	72.7	66.4
4.	Specific costs	Quantitative	EUR/kWh	1.365	1.234	1.277	1.291	1.233
5.	Flexibility in operation	Qualitative	Ling. value	1	2	2	3	3
Environmental criteria								
1.	Aquatic life	Qualitative	Ling. value	–2	–3	–3	–3	–3
2.	Fauna/Flora	Qualitative	Ling. value	–2	–2	–2	–3	–3
3.	Water quality	Qualitative	Ling. value	–1	–1	–1	–2	–2
4.	Air quality	Qualitative	Ling. value	–1	–2	–2	–2	–2
5.	Noise and vibration	Qualitative	Ling. value	–1	–2	–2	–2	–2
6.	Climate Change	Qualitative	Ling. value	2	2	2	2	2
Social criteria								
1.	Resettlement	Qualitative	Ling. value	–1	–3	–3	–4	–4
2.	Loss of land	Qualitative	Ling. value	–1	–3	–3	–4	–4
3.	Cultural heritage	Qualitative	Ling. value	0	0	0	0	0
4.	Traffic and infrastructure	Qualitative	Ling. value	–1	–3	–3	–3	–3
5.	Labour and employment	Qualitative	Ling. value	1	–2	–2	–2	–2
6.	Landscape	Qualitative	Ling. value	–2	–3	–3	–4	–4
7.	Community acceptance	Qualitative	Ling. value	–2	–4	–4	–4	–4

Table 6. The evaluation scale for qualitative criteria

	Definition of impact (linguistic values)
3	Strongly positive: highly beneficial effect, affecting a wide area and/or an important parameter
2	Positive: beneficial effect
1	Small positive: beneficial effect of lesser importance
0	None: no or negligible impact
–1	Small negative: negative impact of limited duration
–2	Negative: undesirable or harmful effect of limited concern
–3	Strongly negative: mitigation possible
–4	Strongly negative: mitigation not possible

9 Results

Along with the previous explanations of the hierarchical structure of decision making and the use of the Java application, the decision maker made the pairwise comparisons to give assessment of importance of criteria groups with respect to the objective (matrix 1 in Table 7), assessment of criteria importance with respect to the corresponding criteria group (matrices 2–4 in Table 7) and the assessment of the priorities of alternatives with respect to each of the criteria (matrices 5–22 in Table 7). The results (priorities of alternatives) are given in Table 8.

Table 7. Pairwise comparisons matrices

Matrix	No.	CR (%)
[1 1 1 | 1 1 1 | 1 1 1 |]	1	0.0
[1 2 3 3 2 | 1/2 1 1 1 1 | 1/3 1 1 1 1 | 1/3 1 1 1 1 | 1/2 1 1 1 1 |]	2	0.71
[1 1 1 1 1 1 | 1 1 1 1 1 1 | 1 1 1 1 1 1 | 1 1 1 1 1 1 | 1 1 1 1 1 1 | 1 1 1 1 1 1 |]	3	0.0
[1 2 3 4 4 4 4 | 1/2 1 2 3 3 3 3| 1/3 1/2 1 2 1 1 1 | 1/4 1/3 1/2 1 1 1 1 | 1/4 1/3 1 1 1 1 1 | 1/4 1/3 1 1 1 1 1 | 1/4 1/3 1 1 1 1 1 |]	4	0.93
[1 1/4 1/3 1/9 1/8 | 4 1 1/2 1/7 1/6 | 3 2 1 1/6 1/6 | 9 7 6 1 1 | 8 6 6 1 1 |]	5	7.28
[1 1/4 1/3 1/9 1/8 | 4 1 1/2 1/7 1/6 | 3 2 1 1/6 1/6 | 9 7 6 1 1 | 8 6 6 1 1 |]	6	7.28
[1 1/4 1/3 1/9 1/8 | 4 1 1/2 1/7 1/6 | 3 2 1 1/6 1/6 | 9 7 6 1 1 | 8 6 6 1 1 |]	7	7.28
[1 1/5 1/4 1/3 1/6 | 5 1 4 4 ½ | 4 1/4 1 2 ¼ | 3 1/4 1/3 1 1/5 | 6 2 4 5 1 |]	8	9.68
[1 1/2 1/2 1/3 1/3 2 1 1 1/2 1/2 | 2 1 1 1/2 1/2 | 3 2 2 1 1 | 3 2 2 1 1 |]	9	0.34
[1 2 2 2 2 | 1/2 1 1 1 1 | 1/2 1 1 1 1 | 1/2 1 1 1 1 | 1/2 1 1 1 1 |]	10	0.0
[1 1 1 2 2 | 1 1 1 2 2 | 1 1 1 2 2 | 1/2 1/2 1/2 1 1 | 1/2 1/2 1/2 1 1 |]	11	0.0
[1 1 1 2 2 | 1 1 1 2 2 | 1 1 1 2 2 | 1/2 1/2 1/2 1 1 | 1/2 1/2 1/2 1 1 |]	12	0.0
[1 2 2 2 2 | 1/2 1 1 1 1 | 1/2 1 1 1 1 | 1/2 1 1 1 1 | 1/2 1 1 1 1 |]	13	0.0
[1 2 2 2 2 | 1/2 1 1 1 1 | 1/2 1 1 1 1 | 1/2 1 1 1 1 | 1/2 1 1 1 1 |]	14	0.0
[1 1 1 1 1 | 1 1 1 1 1 | 1 1 1 1 1 | 1 1 1 1 1 | 1 1 1 1 1 |]	15	0.0
[1 3 3 4 4 | 1/3 1 1 2 2 | 1/3 1 1 2 2 | 1/4 1/2 1/2 1 1 | 1/4 1/2 1/2 1 1 |]	16	0.84
[1 3 3 4 4 | 1/3 1 1 2 2 | 1/3 1 1 2 2 | 1/4 1/2 1/2 1 1 | 1/4 1/2 1/2 1 1 |]	17	0.84
[1 1 1 1 1 | 1 1 1 1 1 | 1 1 1 1 1 | 1 1 1 1 1 | 1 1 1 1 1 |]	18	0.0
[1 3 3 3 3 | 1/3 1 1 1 1 | 1/3 1 1 1 1 | 1/3 1 1 1 1| 1/3 1 1 1 1 |]	19	0.0
[1 4 4 4 4 | 1/4 1 1 1 1 | 1/4 1 1 1 1 | 1/4 1 1 1 1 | 1/4 1 1 1 1|]	20	0.0
[1 2 2 3 3 | 1/2 1 1 33 | (1/2 1 1 2 2 | 1/3 1/3 1/2 1 1 | 1/3 1/3 1/2 1 1 |]	21	1.59
[1 3 3 3 3 | 1/3 1 1 1 1 | 1/3 1 1 1 1 | 1/3 1 1 1 1| 1/3 1 1 1 1 |]	22	0.0

Table 8. Priorities of alternatives

Alternative	Priority
A1	0.2491
A5	0.2182
A3	0.2061
A2	0.1659
A3	0.1603

10 Conclusion

In this paper HPP scheme selection problem formulated as a problem of multicriteria (multi attributive) decision making is solved and a model for evaluation and selection of solution from Pareto set of solutions (HPP scheme alternatives) is developed. The proposed model for multicriteria decision making on the HPP scheme, developed on the principals of sustainable development that includes a relatively large number of criteria (quantitative and qualitative) is applicable in situations where it is difficult to measure criteria or in situations where it is difficult to quantify and measure them. Compared to models based on the other MCDM methods, the advantage of the proposed model based on the Analytic Hierarchy Process method is reflected in the fact that the expert assessments are expressed verbally which is a more realistic presentation of relative importance assessment and the priority of alternatives given by experts. Future research can be carried out to the direction of application of fuzzy numbers and fuzzy logic on the proposed model for multicriteria decision making.

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