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SELECTION OF SMALL HYDROPOWER PROJECT SITE: A MULTI-CRITERIA OPTIMIZATION TECHNIQUE APPROACH

Priyabrata Adhikary, Pankaj Kr Roy and Asis Mazumdar
S. W. R. E., Jadavpur University, Kolkata, India
E-Mail: priyabrata24@gmail.com

ABSTRACT

Small hydropower projects (SHP) are emerging as solution for sustainable, eco-friendly, long term and cost-effective water or renewable energy resource for future. Selecting the appropriate small hydropower project site and its parameters in which to invest is a critical task involving different factors as each project is unique and site specific. Hence such decision-making can be viewed as a multi-criteria optimization problem with correlating criteria and alternatives. This task should take into consideration several conflicting aspects because of the increasing complexity of the socio-political, technological, environmental and economic factors. Traditional single criteria decision-making approaches cannot handle the complexity of such systems. Multi-criteria optimization or MCDA or MCDM methods may provide a better and flexible tool. This paper aims to evaluate applicability of multi-criteria optimization to decision makers during the small hydropower project site selection. To the best of the author's knowledge these novel approaches for application of multi-criteria optimization in small hydropower site selection are absent in renewable energy or water resource or fluid mechanics literature due to its assessment complexity.

Keywords: small hydropower, MCDA, MCDM, VIKOR, TOPSIS, renewable energy, optimization.

1. INTRODUCTION

In India, the total installed power generating capacity during October 2014 was reported as 2, 54, 649.5 MW out of which only 40, 798.8 MW is through hydro power. The identified small hydro power potential sites are 19749.4 MW, installed are 3970.4 MW till November 2014 and under implementation are 895.4 MW [14]. The cost of clean-green-friendly small hydroelectricity is relatively low i.e. Rs2.5/KWH (approx.), compared to others and thus making it a competitive source of renewable energy as demonstrated [1, 2]. Small hydropower projects are complex, interdisciplinary integrated systems, because there are large numbers of civil, mechanical and electrical components with different characteristics. The success of a small hydropower project is no longer dominated by only economic criteria. Several other criteria, such as environmental, social and technical aspects need to be taken into consideration. Therefore, small hydropower project development can be analysed as a typical multi-criteria decision analysis or making (MCDA or MCDM) problem. Inaccurate design, improper selection of project or any parameter will have high negative impact on the overall cost and efficiency. Thus it will result in producing less power at a higher cost-per-watt. Small hydropower projects (i.e. up to 25MW in India) are much more advantageous than conventional medium or large hydropower projects. Small hydropower plant requires very less flow or head compared to conventional hydropower plants. Reservoir is also not required for small hydropower projects as they are mostly run-of-river type. Environmental and social impacts of small hydropower projects are also negligible compared to conventional medium or large hydropower projects [3, 4]. Small hydropower project schemes are classified as: Run-of-river scheme, Canal-based scheme, Dam-Toe scheme, Pumped storage scheme and In Stream type scheme. Run-of-river scheme utilizes the instantaneous river flow without a dam. A weir or a barrage is constructed across the river simply to raise the water level slightly and divert water into a conductor system for power generation. Such a scheme is adopted in the case of a perennial river. Canal fall based schemes are planned to generate power by utilizing the flow and fall in the canal. These schemes may be planned in the canal itself or in the bypass channel. These are low head and high discharge schemes. These schemes are advantageous due to low gestation period, simple layout, no rehabilitation problems and no socio-environmental problems. In Dam-Toe scheme the head is created by raising the water level behind the dam by storing natural flow and the powerhouse is placed at the toe of the dam or along the axis of the dam on either side. The water is carried to the powerhouse through a penstock. Pumped storage scheme is a method of keeping water in reserve for peak period power demands by pumping water that has already flowed through the turbines back up a storage pool above the power plant at a time when customer demand or tariff for energy is low, such as during the middle of the night. The water is then allowed to flow back through the turbine-generators at times when demand is high and a heavy load is placed on the system. Because pumped storage reservoirs are relatively small, construction costs are generally low compared with conventional hydropower facilities. Run of river schemes are also planned in the river itself by with or without creating a barrage and are known as In-stream schemes.

There are two basic components in all four types of SHP schemes; i.e., civil works (Diversion and intake, De-silting tank, Power channel, Fore-bay, Penstock, Powerhouse building, Tail race channel etc.) and electro-mechanical equipment (Valves, Hydraulic Turbine, Generator etc.). Most of the components are same in different types of schemes; some components, however, are different. The development of small hydro projects typically takes from 2 to 5 years to complete, from conception to final commissioning. This time is required to undertake studies and design work, to receive the necessary approvals and to construct the project. Once constructed, small hydro plants require little maintenance over their useful life, which can be well over 35 to 50 years.

Small hydropower project development involves following stages as: Pre-feasibility Analysis; Feasibility Analysis; Engineering and Development; Construction and Commissioning [5, 6]. Small Hydropower Plant operation can be divided under four verticals as: Operation Management, Water Management, Maintenance Management and Personnel Management. Similarly, Small Hydropower Plant maintenance is of four types as: Breakdown Maintenance, Routine Maintenance, Preventative Maintenance and Capital Maintenance. The present scenario of various fields of research in Small hydropower segment can be summarized as:

- Material Science (Effect of corrosion / erosion / water hammer)
- Innovative use of existing civil works (Economic designs by utilizing the existing civil works);
- Equipment standardization (moving away from site specific design to standard equipments);
- Variable speed low head turbine operation (power electronics application);
- Electronic control and telemetry (permits unattended operation of small hydropower projects or AGC);
- Submersible turbo-generators (Eliminate power house hence reduces initial cost);
- Inflatable weirs (efficient use of flexible water-filled rubber weir crests);
- Innovative turbines (various novel types of turbine – fish friendly turbine or pump-turbines);
- Improved design of runner, trash-racks or other hydro turbine parts (self-cleaning or self flushing type);
- Decision Making (Efficient application of various MCDA or MCDM or Multi-criteria optimization tools in Renewable Energy Project optimization);

In the final analysis of any renewable energy research, it is the energy delivered versus the investment cost which has to be optimized for a feasible engineering solution.

2. MATERIALS AND METHODS

Evaluating or making decision of small hydropower project or any of its parameter is a complex analysis as it is always unique and site specific. The use of multi-criteria decision analysis (MCDA) or multi-criteria decision making (MCDM) or multi-criteria analysis (MCA) or multi-criteria optimization techniques can provide a reliable methodology to rank alternatives in the presence of different objectives and limitations [7, 8]. These methods can be used as empirical validation and testing tools of various needs. In addition they can be also applied to group decision making scenario as well as for uncertainty analysis. A review of various published literatures on sustainable energy planning indicates greater applicability of MCDA methods in changed socio-economic scenario. The methods have been very widely used to take care of multiple, conflicting criteria to arrive at better solutions Increasing popularity and applicability of these methods beyond 1990 indicate a paradigm shift in renewable energy planning, development and policy analysis. More research is still to be done to explore the applicability and potentiality of more MCDA methods to real-world planning and designing problems to reduce the gap between theory and practice. Many soft-wares (1000Minds, D-Sight etc.) have also been developed to facilitate such analysis or study. This paper on small hydropower project based decision making is an effort in that direction [9, 10].

A MCDA method is selected and applied to a problem under consideration in order to rank the alternatives. It refers to making decisions in the presence of multiple conflicting criteria. The data and the degree of uncertainty are key factors for the decision-maker when selecting among several MCDA or multi-criteria optimization methods. The performance of different MCDA methods may be compared along varied dimensions, such as perceived simplicity, trustworthiness, robustness and quality in many literatures. Hence, the decision maker also faces the problem of selecting the most appropriate MCDA methods among available ones [9, 11].

The preliminary steps in MCDA method are to formulate the alternatives for sustainable energy decision making problem from a set of selected criteria (technical, economical, environmental, social etc.) and to normalize the original data of criteria. The purpose of normalization is to obtain dimensionless values of different criteria so that all of them can be compared. Secondly, criteria weights are determined to show the relative importance of criteria in MCDA or multi-criteria optimization method. Then, the acceptable alternatives are ranked by MCDA method with criteria weights. Finally, the alternatives' ranking is ordered. If all alternative ranks order in a different MCDA method is just the same, the decision making process is ended. Otherwise, the ranking results are aggregated again and the best scheme is selected [9, 10]. MCDA method classification applicable for water resource as well as renewable energy system includes: Distance Based Methods (TOPSIS, VIKOR etc.), Outranking Methods (ELECTRE-II, PROMETHEE-II etc.), Priority or Utility Based Methods (MAUT/MAVT, SMART etc.), Mixed Category Methods (EXPROM-2, STOPROM-2 etc.) and Fuzzy-MCDM Methods (Fuzzy-TOPSIS, Fuzzy-VIKOR etc.). Distance Based Methods are being applied here for this present site selection problem.

The attributes are of two types, beneficial (i.e. higher values are desired) and non-beneficial (i.e. lower values are desired). A quantitative or qualitative value or its range may be assigned to each identified attribute as a limiting value or threshold value for its acceptance. It is not absolute that more and more criteria are helpful for such decision-making problems [10, 11]. Likewise, less-

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criteria are beneficial to the evaluation of SHP systems. Popular criterion selection methods are Delphi Method, Least Mean Square (LMS) Method etc. All criteria or factors have their internal impact reclassified to a common scale. Weight is assigned to the criteria to indicate its relative importance [11, 12]. Different weights directly influence the results or ranking. Consequently, it is necessary to obtain the rationality and veracity of criteria weights. Three factors are usually considered to obtain the weights: the variance degree of criteria, the independency of criteria and the subjective preference of the decision-makers. Popular weighting methods are Equal Weights Methods, Subjective Weighting Methods (Delphi Method, AHP etc.), Objective Weighting Methods (LMS Method, TOPSIS etc.) and Combined Weighting Methods. Then it is the turn to determine the preference orders of alternative after determining the criteria weights so that MCDA or MCDM Methods are employed to get the ranking order. Usually, the decision maker selects the best alternative based on the ranking orders after the calculation in a selected MCDA method. However, the creditability of a process is necessarily verified so that the results of the ranking orders are computed by a few other MCDA methods sometimes [13, 14]. The application of various MCDA methods of calculation may yield different results. Therefore, the ranking results are necessarily aggregated again and the best scheme from the alternatives is selected. The methods used to aggregate the preference orders are called as aggregation methods (Voting Method, Mathematical Aggregation Method etc.).

3. THEORY AND CALCULATIONS

Distance Based Methods (TOPSIS, VIKOR etc.) are extensively used in any water resources as well as renewable energy project planning and management hence applied to small hydropower project scenario. This may be due to provisions of converting a complex problem into a simple hierarchy, flexibility, intuitive appeal, its ability to mix qualitative as well as quantitative criteria in the same decision framework and use of computational aids leading to successful decisions in many domains. Though there are number of shortcomings the method is popularly used. The applications surveyed have the main objectives of priority setting and have features such as less number of criteria, interaction with decision makers etc. Both VIKOR and TOPSIS methods are based on an aggregating function representing “closeness to ideal”, which originated from the compromise programming method. So VIKOR method as same as TOPSIS, determines the compromise ranking list and the weight stability intervals for preferences stability of the compromise solution. TOPSIS method uses vector normalization but the VIKOR method uses linear normalization. In addition, TOPSIS is preferring an alternative that has the shortest distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS) as the best preferred alternative but VIKOR method calculates ratio of positive and negative ideal solution.

The VIKOR (the Serbian name is ‘Vlse Kriterijumska Optimizacija Kompromisno Resenje’ which means multi-criteria optimization and compromise solution) method was mainly established by Zeleny (2002) and later advocated by Opricovic and Tzeng. This method is developed to solve MCDM problems with conflicting and non-commensurable (attributes with different units) criteria, assuming that compromise can be acceptable for conflict resolution, when the decision maker wants a solution that is the closest to the ideal solution and the alternatives can be evaluated according to all the established criteria. It focuses on ranking and selecting the best alternative from a set of alternatives with conflicting criteria, and on proposing compromise solution (one or more) [15]. The procedural steps for VIKOR method are as follows:

Step-1: Identify the major site selection criteria for a given SHP project and short-list the sites on the basis of the identified criteria satisfying the requirements. A quantitative or qualitative value is assigned to each identified criterion to construct the related decision matrix.

Step-2: a) After short-listing the sites and development of the decision matrix, determine the best, $\mathbf{(m_{ij})_{max}}$ and the worst, $(m_{ij})_{min}$ values for all the criteria.

b) The weights or relative importance of the considered criteria are estimated using Delphi method.

c) Calculate the values of E_i and F_i as mentioned below (when j=1, 2, 3,…M):

$$E_i = L_{1,i} = \sum_{j=1}^{M} w_j \left[(m_{ij})_{max} - m_{ij}\right] / \left[(m_{ij})_{max} - (m_{ij})_{min}\right] \quad (1)$$

Equation (1) is only applicable to beneficial attributes (whose higher values are desirable).

$$E_i = L_{1,i} = \sum_{j=1}^{M} w_j \left[(m_{ij}) - (m_{ij})_{min}\right] / \left[(m_{ij})_{max} - (m_{ij})_{min}\right] \quad (2)$$

Equation (2) is only applicable to non-beneficial attributes (whose lower values are desirable).

Calculate $\mathbf{F_i}$ values as mentioned below:

$$F_i = L_{\infty,i} = \mathrm{Max}^{m} \text{ of } \left\{ w_j \left[(m_{ij})_{max} - m_{ij}\right] / \left[(m_{ij})_{max} - (m_{ij})_{min}\right] \right\} \quad (3)$$

d) Calculate $\mathbf{P_i}$ values as mentioned below:

$$P_i = v((E_i - E_{i\text{-}min})/(E_{i\text{-}max} - E_{i\text{-}min})) + (1 - v)((F_i - F_{i\text{-}min})/(F_{i\text{-}max} - F_{i\text{-}min})) \quad (4)$$

Here $E_{i\text{-}\mathbf{max}}$ and $E_{i\text{-}min}$ are the maximum and minimum values of E_i respectively, and $F_{i\text{-}max}$ and $F_{i\text{-}min}$ are the maximum and minimum values of F_i, respectively. The value of v [weight of the strategy of ‘the majority of attributes’ (or ‘the maximum group utility’)] lies in the range of 0 to 1. Normally, the value of v is taken as 0.5. The compromise can be selected with ‘voting by majority’ ($v > 0.5$), with ‘consensus’ ($v = 0.5$) or with ‘veto’ ($v < 0.5$).

e) Arrange the alternatives in the ascending order, according to the values of P_i. The compromise ranking list for a given v can be obtained by ranking with the P_i

measure. The best alternative is the one having the minimum P_i value.

The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method was developed by Hwang and Yoon (1981). It is a simple ranking method in conception and application. The standard TOPSIS method attempts to choose alternatives that simultaneously have the shortest distance from the positive ideal solution and the farthest distance from the negative-ideal solution. The positive ideal solution maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria. TOPSIS makes full use of attribute information, provides a cardinal ranking of alternatives, and does not require attribute preferences to be independent [8]. The procedural steps for TOPSIS method are as follows:

Step-1: It is based on the concept that the ideal alternative has the best level for all criteria, whereas the negative ideal is the one with all the worst criteria values. The principle is simple: the selected best alternative should have the shortest distance from the positive ideal solution in geometrical sense while it has the longest distance from the negative solution. This makes it easy to locate the ideal and negative ideal solutions.

Step-2: The purpose of normalization is to obtain dimensionless values of different criteria so that all of them can be compared. Normalization is done as follows (where i=1, 2…n and j=1, 2,…m):

$$r_{ij} = \frac{w_{ij}}{\sqrt{\sum_{k=1}^{n} w_{ij}^2}} \quad (5)$$

Step-3: The positive distance between alternative A_i and the ideal solution A^+ is defined as follows:

$$s_i^+ = \sqrt{\sum_{j=1}^{n} (x_{ij} - x_j^+)^2} \quad (6)$$

Where $\mathbf{x}^+$ is the $\mathbf{j^{th}}$ criteria's performance of the ideal solution $\mathbf{A}^+$.

The negative distance is similarly calculated as follows:

$$s_i^- = \sqrt{\sum_{j=1}^{n} (x_{ij} - x_j^-)^2} \quad (7)$$

Where **x-** is the j^{th} criteria's performance of the ideal solution A^-.

Step-4: Finally, the relative closeness degree of A_i and A^+ is defined to:

$$r_i = \frac{S_i^-}{S_i^- + S_i^+} \quad (8)$$

The best alternative is one that has the maximum closeness degree and has the shortest distance to the ideal solution.

Conventional weighting methods are not recommended for the projects requiring social and environmental impact analysis for its approval. Delphi Weighting Method is very popular in these cases. It is a semi-structured communication method, developed as a systematic, interactive forecasting method which relies on engineers, managers or experts. In the standard method, the experts answer the queries in two or more phase. After each phase, a facilitator provides an anonymous summary of the experts' detailed forecasts report. Thus, experts are encouraged to revise their earlier answers in light of the replies of other members of their panel. During this process the range of the answers will decrease and the group will converge towards the "correct" solution. Finally, the process is stopped after a pre-defined stop criterion. The mean or median scores of the final phase or rounds determine the final results. Delphi is based on the principle that decisions from a structured group of individuals are more accurate than those from unstructured groups and has been mentioned as "collective intelligence". The technique can also be adapted for use in meeting individuals and is then termed as mini-Delphi. The main objective of "Delphi Method" was to combine expert opinions on likelihood and expected development time, of the particular technology, in a single indicator. The obtained weights here are: 0.2, 0.1, 0.1, 0.1, 0.2 and 0.3. Based on this method the following scenarios are obtained:

Holistic approach scenario: In this scenario, the stakeholder considers all criteria to be equally important.

Environmental priorities scenario: In this scenario, the stakeholder considers environmental criteria to be most important. The emphasis here is on minimizing environmental impact and health risks as has been used here.

Economical priorities scenario: In this scenario, the stakeholder considers economical criteria to be most important. The emphasis here is minimizing initial, operating and maintenance costs.

Technological priorities scenario: In this scenario, the stakeholder considers technical criteria to be most important. The emphasis here is on efficiency and reliability.

Social priorities scenario: In this scenario, the stakeholder considers socio-political criteria to be most important. The emphasis here is on job creation and social security.

The proposed model composed of VIKOR or TOPSIS method. Spreadsheet based program has been used for solving the same. It consists of four basic stages: identification of properties, weight assigning, evaluation of alternatives and determine final rank by comparison [14, 15]. It is not absolute that more and more criteria are helpful to the renewable energy technology or small hydropower project decision-making. Based on proposed methodology, the present researcher selects some criteria as mentioned in Table-1.

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Table-1. Definition of criteria and alternative.

Small Hydropower Project Site Selection		
Notation	**Criteria**	**Aspects**
X1	Safety Factor	Ecological safety, Plant safety etc.
X2	Social Factor	Job creation, Public Health etc.
X3	Hydrological Factor	FDC, FFA etc.
X4	Economic Factor	Initial cost, Maintenance cost etc.
X5	Technological Factor	Topography, Geology, Efficiency, Reliability etc.
X6	Environmental Factor	Ecology, GHG Emission reduction etc.
Notation	**Alternative**	
A1	Small Hydropower Project Site-1	
A2	Small Hydropower Project Site-2	
A3	Small Hydropower Project Site-3	
A4	Small Hydropower Project Site-4	

4. RANKING OF SHP SITES - VIKOR METHOD

The decision making matrix is formed as mentioned in Table-2.

Table-2. Decision making matrix.

Decision Making Matrix						
	X1	**X2**	**X3**	**X4**	**X5**	**X6**
A1	10.000	7.500	10.000	27.500	25.000	45.000
A2	12.500	13.500	9.000	32.500	15.000	25.000
A3	9.000	10.000	10.500	22.500	35.000	35.000
A4	11.000	9.000	10.000	25.000	25.000	25.000
Utility Function	**MAX**	**MAX**	**MAX**	**MIN**	**MAX**	**MAX**
MAX	12.500	13.500	10.500	32.500	35.000	45.000
MIN	9.000	7.500	9.000	22.500	15.000	25.000
DIFF	3.500	6.000	1.500	10.000	20.000	20.000

The values of E_i, F_i and P_i are obtained for ranking the SHP sites.

Table-3. Ranking of sites and values of E_i, F_i and P_i.

Normalized Set	X1	X2	X3	X4	X5	X6	Ei	Fi	Pi	Rank
Utility Function	MAX	MAX	MAX	MIN	MAX	MAX	Strategy Co-efficient=0.5			
A1	0.143	0.100	0.033	0.050	0.100	0.000	0.426	0.143	0.031	1
A2	0.000	0.000	0.100	0.100	0.200	0.300	0.700	0.300	1.000	4
A3	0.200	0.058	0.000	0.000	0.000	0.150	0.408	0.200	0.182	2
A4	0.086	0.075	0.033	0.025	0.100	0.300	0.619	0.300	0.861	3

5. RANK VALIDATION - TOPSIS METHOD

The same decision making matrix is used as mentioned in Table-2. Then the weighted normalized matrix is formed as shown in Table-4.

Table-4. Weighted normalized matrix.

Weighted Normalized Decision Matrix						
	X1	**X2**	**X3**	**X4**	**X5**	**X6**
Utility Function	**MAX**	**MAX**	**MAX**	**MIN**	**MAX**	**MAX**
A1	0.093	0.037	0.051	0.051	0.096	0.201
A2	0.117	0.066	0.046	0.060	0.058	0.112
A3	0.084	0.049	0.053	0.041	0.135	0.157
A4	0.103	0.044	0.051	0.046	0.096	0.112

Finally the ranks are determined based on Euclidean Distance as shown in Table-5.

Table-5. Ranking of sites and relative closeness.

Euclidean Distance / Relative Closeness						Rank
S1+	0.055	**S1-**	0.098	**C1 (A1)**	0.643	1
S2+	0.118	**S2-**	0.048	**C2 (A2)**	0.287	4
S3+	0.061	**S3-**	0.090	**C3 (A3)**	0.597	2
S4+	0.102	**S4-**	0.044	**C4 (A4)**	0.302	3

6. RESULT AND DISCUSSIONS

The rankings are not significantly affected by the choice of the MCDA or MCDM or multi-criteria optimization methods employed. Exact commercial data are not publicly accessible, but given are generated data based on provided relations which are very close to an actual small hydropower project data (flow, head, cost and capacity etc).

It is observed that all these methods are quite capable to deal with both the cardinal or ordinal data (with finite numbers the cardinal numbers are 0,1, 2, 3 etc. while the ordinal numbers are 1st, 2nd, 3rd etc.; there is really very little difference; but for infinite sets there's a big difference; while cardinal numbers simply measure the size of a set, ordinal numbers describe the structure of a well-ordered set) and can provide the total ranking of the considered alternatives, although they have different mathematical treatments and operational approaches. Here both multi-criteria optimization methods give ranking order as A1-A3-A4-A2. Moreover, the sensitivity analyses have been proved that all methods have provided very similar and stable rankings. Given the subjectivity of decision maker judgment, these results are satisfactory. So basically, all these multi-criteria optimization methods whether they adopt preference function or weighted sum utility value, indicate how much an alternative is preferred to other alternatives. The minor discrepancy that may appear between the intermediate rankings obtained by different methods can be attributed to the difference in their mathematical and operational approaches to select the best alternative, the way of dealing with criteria weights in their calculations and introduction of additional parameters affecting the final ranking of the alternatives. In few other cases where strong disagreement between these methods occurs, it is due to presence of mixed ordinal-cardinal data in the decision matrix. Thus, the focus would lie not on the selection of the most appropriate preference ranking method to be adopted, but on proper structuring of the decision problem considering relevant criteria and decision alternatives.

In sensitivity analysis, the ranking reversal of the alternatives is checked by changing the weights of relative importance of the attributes. The decision maker can check the ranking reversals by changing the weights (of relative importance) of the attributes by a percentage. However, it is obvious that if the assigned weights are changed, then the chances for rank reversals of the alternatives increase. Once the decision maker is clear about the relative importance of the attributes and assigns accordingly, then there is no need to check the ranking reversals simply by changing the weights if required.

6. CONCLUSIONS

Evaluating and selecting small hydropower project site is a complex analysis that can be defined as a multi-dimensional space of different indicators and objectives. The uses of MCDM or MCDA or multi-criteria optimization techniques provide a reliable methodology to rank alternatives of renewable energy resources (small hydro) in the presence of different objectives and limitations. Even with the large number of available multi-criteria optimization methods, none of them is considered the best for all kinds of decision-making situations.

Different methods often produce similar or different results even when applied to the same problem using same data due to various modeling methods. There is no better or worse method but only a technique that fits better in a certain situation. Thus, it can be said that although the mathematical and operational procedures of the considered preference ranking methods substantially differ from each other, but there are similarities in the concepts they use to reach the final evaluation and ranking of the alternatives in terms of overall utility or significance or preference rating. Hence rank validation by a different method along with final physical verification by the experts is highly recommended for small hydro (water resource or renewable energy) decision making process. The goal of this research is to investigate how multi-criteria optimization techniques can be applied in order to provide better decision aiding for stakeholders in optimal small hydropower project development. This research work and the accompanying case studies have been carried out by renewable energy engineers and not by experts in decision analysis. Accordingly, the main focus of the work is on the efficient application of various multi-criteria decision analysis (MCDA) or multi-criteria optimization methods for optimal small hydropower project development purposes, and not on the theoretical distinctions between the various methods. This research is motivated by the need to help planners, developers or consultants to cope with the changes in concepts and values concerning the planning, development, operation and maintenance of local sustainable energy supply systems.

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