Multi-Criteria Decision Making Using Relative Ratio Method for Locating a Small Hydropower Plant in Central Greece.

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Abstract: - The selection of the best location for the placement of a small hydropower plant is an important issue on engineering because it affects the cost effectiveness of the investment and the environment (mainly local), too. This paper deals with the selection of the optimal location of a small hydropower plant among several candidate sites (eight alternative locations in Central Greece), based on multi-criteria analysis. Techno-economic analysis was the only criteria for locating a hydropower plant until now. In this paper the Multiple Criteria Decision Making theory was selected in order to find the optimum location of a small hydropower plant, under complex circumstances. The multicriteria method that was selected is Relative Ratio (RR). For the evaluation of the criteria and the weights of the problem the Analytic Hierarchy Process (AHP) method was used. After the preliminary study of the hydropower plants, the selection and analysis of the eleven criteria, for the rating of the alternative positions as well as the weights took place. Finally, using the RR method, the alternatives were ranked and the optimum location for placing the small hydropower plant was obtained.

Key-Words: - Small Hydropower Plant, Multi-criteria analysis, Relative Ratio, Optimal location

1 Introduction

Energy consumption is one of the largest issues on earth. The modern lifestyle has demanded large amounts of energy. Last decades people are searching and fight for energy sources. Unfortunately, even today most of the energy is covered from fossil fuels (like diesel, gas etc.). This phenomenon is causing environmental problems from gas emissions such as greenhouse effect and for this reason more environmental friendly sources of energy, like renewable sources, are seeked and utilized (Mishra et al., 2011, Aslam et al., 2008).

Hydropower is the oldest renewable source of energy used by people. It exploits the dynamic energy of water and produces electric power. The location of a small hydropower station may influence the output power and the cost effectiveness of the investment. Until today, techno-economic analysis is the only criteria for locating a small hydropower plant. In this paper we took into consideration all the criteria that influence the decision for the placement. These criteria are economic, environmental, social-political and technical, thus a multicriteria analysis was carried out.

The fact that the solution of complex and important decision-making problems cannot be achieved through a one-sided and one-dimensional analysis, since reality is multidimensional, has led to the development and dissemination of Multiple Criteria Decision Making (MCDM). In the real world there are many criteria that should be taken into consideration in decision making problems. These criteria usually conflict with each other because they represent different effects. So, there is not one solution satisfying all criteria, in the best case, simultaneously. These problems are called Multiple Criteria Decision Making. Optimization with MCDM is the process of determining the best feasible solution according to established criteria. So, the solution is a compromise solution (Roy, 1996, Zeleny, 1982, Hong & Cho, 1999, Kersten & Mallory, 1990, Loukas, 2004).

2 Method

2.1 Relative Ratio (RR)

The Relative Ratio (RR) method classifies and selects a set of alternative activities with the existence of a set of conflicting criteria at the same time. The RR method is a development of the VIKOR method and according to it a compromise solution (or a ranking list) is determined, provided that the selected alternative activity should be as close as possible to the ideal solution and at the same time as far away from the negative ideal solution. For this purpose, a ranking index ξ whose measure meets the above requirement is introduced into this method. The above method was proposed in 2009 by Li (Li, 2009), which gave a broad analysis of this method and its contrast with the existing compromise methods TOPSIS and VIKOR.

As in the VIKOR method, Li (2009) sets the following problem to solve: the decision-maker is required to select an alternative activity from a set f_i $(i = 1,2,\dots,m)$ to rank the same set, based on n criteria x_j $(j = 1,2,\dots,n)$. Therefore, we consider a set of criteria $X = \{x_1, x_2, \dots, x_n\}$.

Based on the above, the decision matrix is determined first:

$$F = (f_{ij})_{mxn} = \begin{matrix} \\ f_1 \\ f_2 \\ \cdots \\ f_m \end{matrix} \overbrace{\begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ f_{m1} & f_{m2} & \cdots & f_{mn} \end{bmatrix}}^{x_1 \quad x_2 \quad \dots\dots\dots \quad x_n},$$

$$f_{ij} = f_i(x_j)$$

The sums are then calculated:

$$\sum_{i=1}^{m} f_{ij}, \quad j = 1,2,\dots,n$$

The initial decision record is therefore normalized as follows (Deng et al., 2000):

$$r_{ij} = \frac{f_{ij}}{\sum_{i=1}^{m} f_{ij}}$$

And the normalized matrix is given as follows:

$$r = (r_{ij})_{mxn} = \begin{matrix} \\ f_1 \\ f_2 \\ \cdots \\ f_m \end{matrix} \overbrace{\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}}^{x_1 \quad x_2 \quad \dots\dots\dots \quad x_n}$$

The ideal solution f^+ $(f^+ \notin F)$, which in its normalized form is $f^+_{norm} = g = [g_1, g_2, \dots, g_m]$ and the negative ideal solution f^- $(f^- \notin F)$ which in its normalized form is $f^-_{norm} = b = [b_1, b_2, \dots, b_m]$.

The difference now between the alternative activity f_i and the ideal solution f^+ can be measured with the weighted distance of Minkowski, (or L_p-metric) $d_p(f_i, f^+) = \left\{ \sum_{j=1}^{m} [w_j(g_j - r_{ij})]^p \right\}^{1/p}$ and the difference between the alternative activity f_i and the negative ideal solution f^- can be measured with the weighted distance of Minkowski, (or L_p-metric) $d_p(f_i, f^-) = \left\{ \sum_{j=1}^{m} [w_j(r_{ij} - b_j)]^p \right\}^{1/p}$, where w_j is the weights or preferences of the decision maker. Thus, for $p = 1$, we have the weighted Hamming distance $d_1(f_i, f^+) = \sum_{j=1}^{m} [w_j(g_j - r_{ij})]$, for $p = 2$, we have the weighted Euclidean distance $d_2(f_i, f^+) = \sqrt{\sum_{j=1}^{m} [w_j(g_j - r_{ij})]^2}$ and finally for $p \to +\infty$, we have the weighted distance of Chebyshev $d_\infty(f_i, f^+) = \max_{1 \le j \le m} \{ w_j(g_j - r_{ij}) \}$. The alternative solution f_i which have the minimum distance $d_p(f_i, f^+)$ from ideal solution doesn't means that it has also the maximum distance from negative ideal solution $d_p(f_i, f^-)$. If $d_p(f^+)$ is the minimum distance from ideal solution and $d_p(f^-)$ is the maximum distance from negative ideal solution then $\xi_p(f_i) = \frac{d_p(f_i, f^-)}{d_p(f^-)} - \frac{d_p(f_i, f^+)}{d_p(f^+)}$ $(\xi_p \le 0)$ is the RR index. The alternative f_i with the maximum ξ_p is the best solution.

2.2 Analytic Hierarchy Process (AHP)

The degree of importance of the criteria applied for the assessment of the various alternative scenarios is determined by the weighting factor attributed to these criteria. For the weight and criteria ranking, comparisons of weights and the

alternatives for each criterion were created in accordance with Saaty's theory, which is applied for decision making with the AHP method (Saaty, 1977, 1980, 1990, 1994, 2006, 2008).
The AHP method is based on decomposing a complex MCDM problem into a system of hierarchies. There is a fundamental 1–9 scale of absolute numbers shown in Table 1, in order to design the hierarchy. AHP method does not measure any factor interacting with an alternative proposal or criterion individually but in relative comparison with a corresponding factor. In short, it marks the significance of one factor as compared to the importance of someone else, based exclusively on binary comparisons, which provide, through the Saaty scale, the measurable result (Kollia, 2012).
The values ultimately attributed to each criterion and to each alternative are presented in the form of a table (decision log) to each multi-criterion decision problem. The Scoreboard or Decision Register or Consistency Chart or Comparison Table is a major feature of multi-criteria analysis. In it, the columns represent the evaluation criteria and the options lines. Each performance evaluation is usually a numeric value. That is, x_{ij} of such a table expresses the performance of the alternative or scenario i with respect to criterion j (Hwang & Yoon, 1981).

Table 1. *Fundamental Scale of Absolute Numbers*

Intensity of Importance	Definition	Explanation
1	Equal Importance (E.I.)	Two activities contribute equally to the objective
3	Moderate importance (M.I.)	Experience and judgment slightly favor one activity over another.
5	Strong importance (S.I.)	Experience and judgment strongly favor one activity over another.
7	Very strong importance (V.S.I.)	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance (EX.I.)	The evidence favoring one activity over another is of the highest possible order of affirmation
Intensities of 2, 4, 6 and 8 can be used to express intermediate values.		

The fact that the method itself provides the ability to measure the consistency of judgments is radically separate from most analytical decision making methods which have no formal form of consistency control, and for this reason makes it one of the most widely used methods. The consistency check for each criterion is necessary and the consistency ratio must be less than 0.1 (or 10%), which means that the scores of the alternative proposals for the criteria are consistent.

3 Case Study

3.1 General

A case study took place in order to find the best location for placing a small hydropower plant in Central Greece. There were chosen three basins and in one basin chosen three different basins in order to extract results for the model application in the same river. More specifically, feasibility study of hydropower plants was occurred. The five alternative locations for placing the small hydropower plant are: X_1=Bathilakkos, X_2=Filakti, X_3=Karitsa, X_4=Karitsa II, X_5=Karitsa III.

3.2 Criteria

Criteria should cover any aspect of the problem and have the minimum number. The choice of criteria, and their weights, is subjective. Therefore, the choice of the criteria and their weights must be in line with the following assumptions (Keeney & Raifa, 1993):

- Completeness: all the key points of the problem must be covered.

- Functionality: must be attributable to numerical values.
- There should be no unnecessary criteria, nor a criterion within one another.
- The dimensions of the problem must be kept to a minimum.

Unfortunately, the selection criteria are not based on a sufficiently well-defined methodology. However, there are some techniques that help to make the best choice. Roy et al. (1986) studied the various views on determining factors, after extensive analysis, with the aim of highlighting, their classification from minimal to maximum significance. Keeney & Raiffa (1976), Keeney (1988) and Saaty (1980) advocated a hierarchical way of constructing reverse ranking criteria by Roy, through the synthesis of the various views, into their sub-elements, until appropriate approach. In the Greek bibliography, Skordilis, (1989) and Diakoulaki et al., (1995) choose to evaluate as many criteria as possible to cover the widest possible range of goals (Aravossis et al., 2001; Soderberg & Kain, 2002; Etnier & Soderberg, 2002).
Brans (1996) suggests that criteria should be classified into more general categories. Thus, it categorizes the four following different types of selection criteria for multi-criteria evaluation of alternative development projects:

- Economic
- Technical
- Social
- Environmental

The main criteria were determined using extensive library studies and experts' opinion. The selection criteria presented in the following table.
Firstly, the decision maker constructs the pair-wise comparison matrix of the criteria (Table 3). Since the consistency ratio (C.R.) is less than 0.1 or close, the judgments are acceptable. Finally, in order to calculate the weights of the criteria, according to Saaty's method, the eigenvector is calculated (Table 4), which depicts the importance of each criteria or the weights. In Figure 1 the column chart, whose values derive from Table 4, shows the weights' comparison across the criteria.

3.3 Decision Matrix

The scoring of every alternative for every criteria is the decision matrix. The alternatives are compared with pair-wise comparisons for each criterion using Saaty's method. The eigenvectors, which are calculated for each criterion, form the columns of the decision matrix (Table 5).

Table 2. *Criteria for the evaluation of multicriteria analysis.*

ECONOMIC (2 CRITERIA)	C1. Initial cost of the investment. C2. Profit (Internal Rate of Return).
SOCIAL-POLITICAL (4 CRITERIA)	C3. Area needs to electricity. C4. Ability to use water downstream. C5. Coverage of downstream water uses. C6. Social and political acceptance (and environmental organizations).
ENVIRONMENTAL (2 CRITERIA)	C7. Effects on the fauna and fishpond of the area. C8. Environmental impacts.
TECHNICAL (3 CRITERIA)	C9. Annual electricity production. C10. Risk - Reliability of benefits. C11. Area accessibility.

Table 3. *Comparison matrix of the weights*

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C1	1	1/2	5	6	4	8	3	2	1	3	7
C2	2	1	6	7	5	9	4	3	2	4	8
C3	1/5	1/6	1	2	1/2	4	1/3	¼	1/5	1/3	3
C4	1/6	1/7	1/2	1	1/3	3	1/4	1/5	1/6	1/4	2
C5	1/4	1/5	2	3	1	5	1/2	1/3	1/4	1/2	4
C6	1/8	1/9	1/4	1/3	1/5	1	1/6	1/7	1/8	1/6	1/2
C7	1/3	1/4	3	4	2	6	1	½	1/3	1	5
C8	1/2	1/3	4	5	3	7	2	1	1/2	2	6
C9	1	1/2	5	6	4	8	3	2	1	3	7
C10	1/3	1/4	3	4	2	6	1	0,5	1/3	1	5
C11	1/7	1/8	1/3	1/2	1/4	2	1/5	1/6	1/7	1/5	1

Table 4. *Eigenvector—Criteria's weights*

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
0,167	0,243	0,038	0,027	0,054	0,015	0,078	0,114	0,167	0,078	0,019

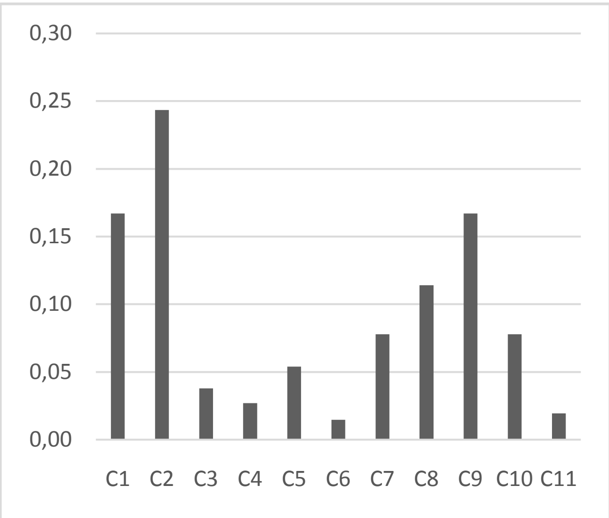

Fig. 1. Importance of each criterion after AHP evaluation.

3.4 Results

The Relative Ratio method, which is a MCDM method, was applied in order to classify the alternative locations for placing the small hydropower plant. In order to achieve this and find the optimal location the decision maker used a program in Visual Fortran. The RR indexes ξ_1, ξ_2 and ξ_∞ calculated and the classification of the alternatives was obtained.

- For ξ_1 the classification is:
  X_4 (0.00) > X_5 (-0.09) > X_2 (-0.29) > X_3 (-0.37) > X_1 (-0.95)
- For ξ_2 the classification is:
  X_5 (-0.03) > X_4 (-0.05) > X_3 (-0.21) > X_2 (-0.63) > X_1 (-1.16)
- For ξ_∞ the classification is:
  X_3 (-0.03) > X_5 (-0.06) > X_4 (-0.27) > X_2 (-0.72) > X_1 (-1.13)

In table 6 the results of the RR indexes are presented in classification order.

Table 5. *Decision matrix after AHP evaluation.*

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
X_1	0.04	0.05	0.06	0.06	0.35	0.38	0.44	0.16	0.15	0.22	0.39
X_2	0.39	0.12	0.14	0.44	0.49	0.38	0.24	0.07	0.04	0.33	0.12
X_3	0.21	0.33	0.26	0.17	0.06	0.08	0.09	0.10	0.19	0.14	0.12
X_4	0.24	0.28	0.26	0.17	0.06	0.08	0.15	0.40	0.17	0.14	0.12
X_5	0.12	0.22	0.26	0.17	0.06	0.08	0.09	0.26	0.45	0.16	0.23

Table 6. *Relative Ratio application results* (ξ_p).

Alternative	ξ_1	Classification	ξ_2	Classification	ξ_∞	Classification
X_1	-0.95	5	-1.16	5	-1.13	5
X_2	-0.29	3	-0.63	4	-0.72	4
X_3	-0.37	4	-0.21	3	-0.03	1
X_4	0.00	1	-0.05	2	-0.27	3
X_5	-0.09	2	-0.03	1	-0.06	2

4 Conclusion

This paper presents the first application of Relative Ratio method to solve the problem for placing a small hydropower plant. Relative Ratio method is a Multi-criteria Decision Making method which have the advantage that it takes into consideration more parameters than techno-economic feasibility and analysis.

Parameters or criteria, like environmental or social, which have quality characteristics and not quantity took into consideration which is very important. This advantage is possible by using Analytic Hierarchy Process. The Analytic Hierarchy Process was used for the criteria and weight ranking.

Classification of the alternatives is different for every Relative Ratio index (ξ_1, ξ_2, ξ_∞). For ξ1 index best solution is X_4 alternative (Karitsa II), for ξ_2 is X_5 alternative (Karitsa III) and for ξ_∞ is X_3 (Karitsa) alternative. These solutions have little differences between them. This fact was expected because these alternatives are in the same river. So, the best river for placing the small hydropower plant is the Karitsa River. On the other hand, the worst alternative in all cases is X_1 alternative (Bathilakkos).

Finally, this application shows that Relative Ratio method could also be implemented in various multi-criteria engineering problems.

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