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AHP-BASED APPROACH TO EVALUATE SOLAR POWER PLANT LOCATION ALTERNATIVES

Abstract:

Solar energy is the most readily available source of energy, and one of the most important sources of the renewable energy, because it is non-polluting and helps in lessening the greenhouse effect. Main problem of establishing a solar power plant is to determine its location. In the presence of many location alternatives and evaluation criteria, a multiple-criteria decision making problem arises. In this work, the location problem will be solved by using analytic hierarchy process (AHP) to figure out the most satisfying alternative. A numerical example is also included to show the proposed methodology in Turkey. . . . .

Keywords:

Solar energy, multiple-criteria decision making, analytic hierarchy process

JEL Classification: C00

Introduction

Every day, the sun sends out an enormous amount of energy, called solar energy. It radiates more energy in one second than the world has used since time began. This energy comes from within the sun itself. Like most stars, the sun is a big gas ball made up mostly of hydrogen and helium gas. The sun makes energy in its inner core in a process called nuclear fusion. Only a small part of the solar energy that the sun radiates into space ever reaches the earth, but that is more than enough to supply all our energy needs. Every day enough solar energy reaches the earth to supply our nation's energy needs for a year. It takes the sun's energy just a little over eight minutes to travel the 93 million miles to earth. Solar energy travels at a speed of 186,000 miles per second, the speed of light. Today, people use solar energy to heat buildings and water and to generate electricity. Solar energy has great potential for the future. Solar energy is free, and its supplies are unlimited. It does not pollute or otherwise damage the environment. It cannot be controlled by any one nation or industry. If we can improve the technology to harness the sun's enormous power, we may never face energy shortages again.

Solar power plant location problem is typical multiple-criteria decision making (MCDM) problem in the presence of various selection criteria and a set of possible alternatives. Among the available multi-attribute approaches, only the analytic hierarchy process (AHP) approach, first introduced by Saaty (1981) has the capabilities to combine different types of criteria in a multi-level decision structure to obtain a single score for each alternative to rank the alternatives (Yurdakul, 2004). In AHP, a hierarchy considers the distribution of a goal amongst the elements being compared, and judges which element has a greater influence on that goal.

In this paper, an intelligent approach to solar power plant location problem through AHP is proposed to find out the best satisfying solar power plant location alternative. In addition, to prove the applicability of the proposed approach, a numerical example is presented.

In literature, the AHP method has been applied to many complex real-world multi-criteria decision-making problems in recent literature as an emerging solution approach (Albayrakoglu, 1996; Carlsson and Walden, 1995). It has been used in a wide variety of complex decision making problems, such as the strategic planning of organizational resources (Saaty, 1981), the evaluation of strategic alternatives (Yand and Lee, 1997), and the justification of new manufacturing technologies (Albayrakoglu, 1996). An earlier survey provided over 200 known AHP applications (Zahedi, 1986). The AHP has also been applied in a variety of formats such as: the design tool for large-scale systems or composite ratio scales (Weiss and Rao, 1987), the instrument for pairwise comparison in the application of artificial neural networks (Wang et al., 1997) and the primary structure of decision support systems (Zahedi, 1986). As an effective methodology, the AHP approach has been used to determine the optimal facility location site among alternatives under multiple criteria (Carlsson and Walden, 1995; Yang and Lee, 1997), and to identify objective coefficient and parameter values in multiple-objective LP problems (Korhonen and Wallenius, 1990). Meade and Presley (2002) used the AHP method for R&D project selection problem.

Proposed Approach

In this study, a multiple-criteria decision making approach through the AHP method is proposed to evaluate a set of solar power plant location alternatives in terms of evaluation main criteria with their related criteria. The approach also helps the decision-maker(s) construct a framework (called AHP hierarchy) that is a schematic representation of the problem. The overall objective of this hierarchy is to find out the best location alternative. To construct this hierarchy, firstly, the decision-maker(s) should determine necessary elements (i.e. main criteria, criteria and alternatives). These elements are very critical at the stage of the evaluation, and should be well-defined due to the fact that they play important role in finding out the best alternative out of the available options.

The AHP method consists of a systematic approach based on breaking the decision problem into a hierarchy of interrelated elements. The evaluation of selection attributes is done using a scaling system showing that each criterion is related with another. This scaling process is then converted to priority values to compare alternatives. Table 1 shows this nine-point scale scheme of Saaty's (Saaty, 1989).

Table 1: Nine-point scale of Saaty's

Rating	Judgment or Preference	Remarks
1	Equally important	Two attributes contribute equally to the attribute at the higher decision level
3	Moderately more important	Experience and judgment slightly favour one attribute over another
5	Strongly more important	Experience and judgment strongly favor one attribute over another
7	Very strongly more important	Experience and judgment strongly favour one attribute over another; its dominance has been demonstrated in practice
9	Extremely more important	Experience and judgment extremely favour one attribute over another; the evidence favouring one attribute over another is of the highest

Using AHP method in multiple-criteria decision making process one has to be aware that the result obtained allows compensatory rules. This means that a bad performance of certain criterion can be completely compensated by a good performance of another criterion. In the AHP, the alternatives that are deficient with respect to one or more objectives can be compensated by their performance with respect to other objectives. So that using the AHP model in a decision making process to obtain the best choice of alternatives compared, which are the acceptable or passing grade performance with the actual performance, means allowing compensation of bad performance indicators by good indicators. So, the AHP is a popular method for tackling multi criteria analysis problems involving qualitative data, and has successfully been applied to many actual decision situations. The steps of the AHP method are presented next (Saaty, 1981).

Step 1. Define the problem and determine its goal.

Step 2. Structure the hierarchy from the top (the objectives from a decision maker's view point) through the intermediate levels (criteria on which subsequent levels depend) to the lowest level which usually contains the list of alternatives.

Step 3. Construct a set of pair-wise comparison matrices (size nxn) for each of the lower levels with one matrix for each element in the level immediately above by using the relative scale measurement. The pair-wise comparisons are done in terms of which element dominates the other.

Step 4. There is n(n-1)/judgments required to develop the set of matrices in Step 3. Reciprocals are automatically assigned in each pair-wise comparison.

Step 5. Hierarchical synthesis is now used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.

$$Ax = \lambda_{\max} x \tag{1}$$

where, A indicates pairwise comparison matrix, x is weight column vector, and $\lambda_{\max}$ is eigenvalue of matrix A.

Step 6.Having made all the pair-wise comparisons; the consistency is determined by using the eigenvalue $\lambda_{\max}$, to calculate the consistency index, CI as follows;

$$CI = (\lambda_{\max} - n)/(n-1) \tag{2}$$

Where n is the matrix size. Judgment consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value.

$$CR = CI / RI \tag{3}$$

The CR is acceptable, if it does not exceed 10%. If it is more, the judgment matrix is inconsistent. To obtain a consistent matrix, judgments should be reviewed and improved. RI is the average index for randomly generated weights (Saaty, 1981).

Steps 3-6 are performed for all levels in the hierarchy.

The priority weight of each alternative can be obtained by multiplying the matrix of evaluation ratings by the vector of attribute weights and summing over all attributes. Expresses in conventional mathematical notation (Saaty, 1981);

Weighted evaluation for alternative k; $k = \sum_{i=1}^{t} \left(criterionweight_i x evaluationrating_{ik} \right)$ (4)

for i=1, 2..., t (t: total number of evaluation criteria)

After calculating the weight of each alternative, the overall consistency index is calculated to make sure that it is smaller than 10% for consistency on judgments.

If it is more, the judgment matrix is inconsistent. To obtain a consistent matrix, judgments should be reviewed and improved by the decision-maker(s).

Case Study

In this paper, an approach is proposed to find out the best solar power plant location among possible alternatives in terms of a set of evaluation criteria for the case of Turkey. The solar energy is an excellent source for this country, as one of the highest density regions of solar powers, and it is always free and supplies are unlimited. In this case study, we need to determine a new location due to the fact that especially for ten years, Turkey has needed to have more energy supplies in various sectors as its economic growth is getting better. In addition, because of the sun’s enormous power, we may never face energy shortages again in future of the country. That is why; we focused on this case study to show the applicability of the proposed method explained step-by-step next.

According to the Step 1 and Step 2 of the AHP method (in Section 2), first the elements (i.e. main criteria, criteria and alternatives) are determined by utilizing a previous study done by Ayag and Samanlioglu (2010), and shown in Table 2. Later, the AHP hierarchy is constructed and illustrated in Figure 1.

Table 2: Definition of elements for the problem

Geographical Factors (GF)	Land work (LW) Number of sunny days (SD) Sun light radiation (SR) Low wind speed (WS) Air pollution (AP) Amount of rainfall (AR)
Economic Factors (EF)	Energy cost (EC) Government encouragement (GE) Land cost (LC)
Social Factors (SF)	Labor supply (LS) Safety (SA) Community attitudes (CA) Economic contribution to the region (ER)
Location Alternatives	Baskale (A) Elmalı (B) Taskent (C) Yüksekova (D)

In Step 3-5, first pairwise comparison matrices for alternatives (A, B, C, and D) in terms of each criterion are constructed by using nine-point scale in Table 1. For example, for the pairwise comparison matrix of alternatives in terms of Criterion 1 (LW) is shown in Table 3.

Table 3: Pairwise comparison matrix of alternatives in terms of Criterion 1 (LW)

For LW	A	B	C	D	Weights
A	1,000	7,000	9,000	5,000	0,660
B	0,143	1,000	3,000	3,000	0,182
C	0,111	0,333	1,000	1,000	0,072
D	0,200	0,333	1,000	1,000	0,087
				λ_{max}	4,206
				CI	0,069
				CR	0,061

Pairwise comparison matrix, A

Weight vector, x

To calculate weight vector, x, first we sum the values in each column of matrix A. Second, we divide each element of the column by the column total. Finally, we get average of each line of A, to obtain x.

By referring to (1), we can obtain λ_{max} eigenvalue as shown in Table 3. Later, we can also calculate the CI and CR values as follows:

We also use Step 5 to check out that the judgments of for decision-maker(s) are consistent. For example, for pairwise comparison matrix in Table 3, the following calculations referring to (2) and (3) are done:

$$CI = (4{,}206 - 4)/(4-1) = 0{,}069$$

$$CR = 0{,}069/1{,}12 = 0{,}061$$

As seen here, CR value is 0,061 which is less than 0.10, and it means the pairwise comparison matrix, A is consistent.

By following the same way, 12 more pairwise comparison matrices for the remaining criteria, and 1 matrix for evaluation criteria are constructed using nine-point scale. The results are shown in Table 4 and 5.

Finally, by using data in Table 5, referring to (5), we can obtain final weights and ranking alternatives as given in Table 6. As seen in Table, first alternative, Baskale (A) with highest weight (0,574) is found as the best alternative.

Table 6: Final ranking of alternatives

Alternatives	Weights	Ranking
Baskale (A)	0,574	1
Elmalı (B)	0,228	2
Taskent (C)	0,105	3
Yüksekova (D)	0,093	4

Conclusions

In this paper, an AHP-based methodology for solar power plant location selection problem has been proposed by taking into consideration quantitative and qualitative elements to evaluate the location alternatives. This approach presents a very strong decision making tool help decision-makers to take an action for selection problems. On the other hand, if the number of evaluation criteria reaches to high level, the solution process can take more time-consuming and might not help the decision-maker(s) make a practical decision. On the other hand, the proposed method can be used by any decision-makers easily by making their judgments through an Excel template with Saaty's nine-point scale.

Furthermore, a case study has been presented to show the applicability of the proposed method. In this case study, a new location, Baskale was determined for the case of Turkey that needs to have more energy supplies in various sectors as its economic growth develops.

For future study, a knowledge-based (KB) or an expert system (ES) can be integrated to help decision-makers both make pair wise calculations more concisely, and interpret the results in each step of the AHP.

Figure 1: AHP hierarchy of the solar power plant location problem

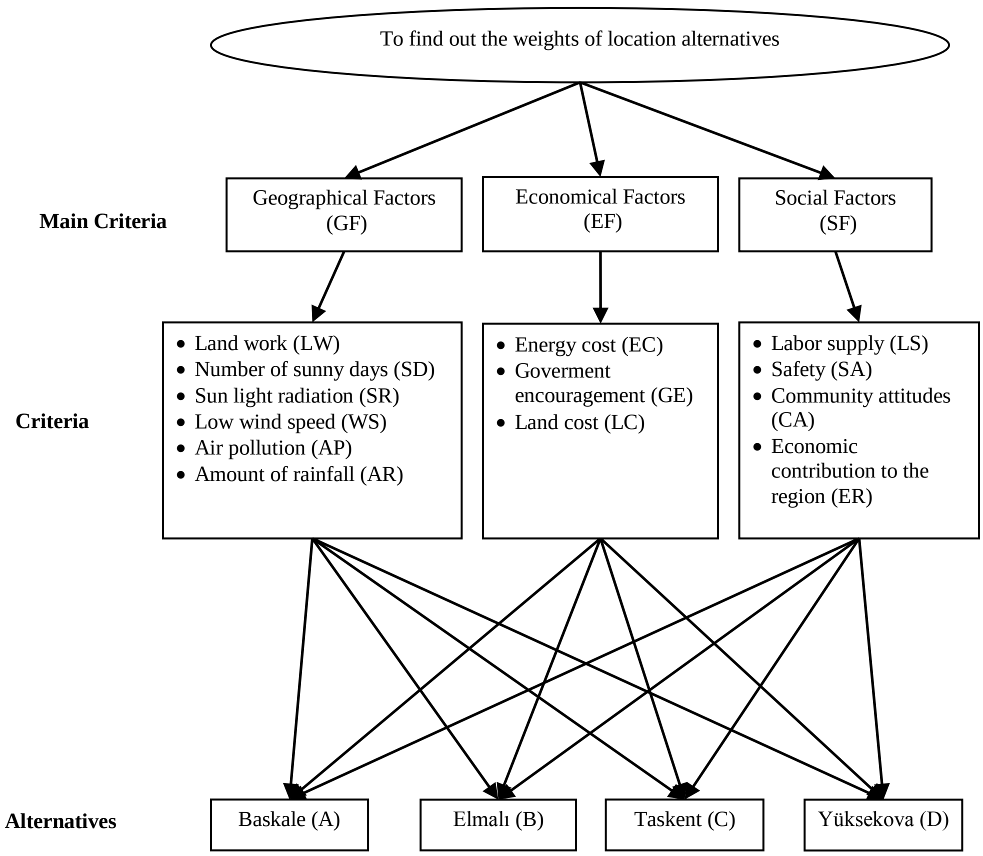

Table 4: Pairwise comparison matrix of the evaluation criteria

	LW	SD	SR	WS	AP	AR	EC	GE	LC	LS	SA	CA	ER	Weights
LW	1,000	1,000	3,000	3,000	7,000	9,000	5,000	7,000	5,000	7,000	9,000	7,000	9,000	0,226
SD	1,000	1,000	1,000	1,000	9,000	7,000	3,000	5,000	7,000	9,000	9,000	7,000	9,000	0,192
SR	0,333	1,000	1,000	1,000	3,000	9,000	5,000	3,000	3,000	3,000	7,000	9,000	7,000	0,142
WS	0,333	1,000	1,000	1,000	1,000	3,000	1,000	1,000	1,000	5,000	9,000	3,000	3,000	0,089
AP	0,143	0,111	0,333	1,000	1,000	1,000	3,000	3,000	3,000	3,000	3,000	3,000	7,000	0,072
AR	0,111	0,143	0,111	0,333	1,000	1,000	1,000	5,000	5,000	3,000	3,000	5,000	3,000	0,064
EC	0,200	0,333	0,200	1,000	0,333	1,000	1,000	3,000	1,000	3,000	3,000	1,000	5,000	0,054
GE	0,143	0,200	0,333	1,000	0,333	0,200	0,333	1,000	3,000	1,000	1,000	5,000	3,000	0,044
LC	0,200	0,143	0,333	1,000	0,333	0,200	1,000	0,333	1,000	1,000	1,000	1,000	1,000	0,031
LS	0,143	0,111	0,333	0,200	0,333	0,333	0,333	1,000	1,000	1,000	1,000	1,000	1,000	0,023
SA	0,111	0,111	0,143	0,111	0,333	0,333	0,333	1,000	1,000	1,000	1,000	1,000	1,000	0,020
CA	0,143	0,143	0,111	0,333	0,333	0,200	1,000	0,200	1,000	1,000	1,000	1,000	1,000	0,024
ER	0,111	0,111	0,143	0,333	0,143	0,333	0,200	0,333	1,000	1,000	1,000	1,000	1,000	0,019

Table 5: Weighting of solar power plant location alternatives

Criteria > Alternatives	LW (0,226)	SD (0,192)	SR (0,142)	WS (0,089)	AP (0,072)	AR (0,064)	EC (0,054)	GE (0,044)	LC (0,031)	LS (0,023)	SA (0,020)	CA (0,024)	ER (0,019)
A	0,670	0,634	0,447	0,434	0,581	0,488	0,459	0,622	0,625	0,666	0,653	0,675	0,511
B	0,149	0,178	0,280	0,351	0,241	0,330	0,334	0,175	0,222	0,188	0,182	0,164	0,321
C	0,088	0,076	0,171	0,117	0,094	0,096	0,133	0,140	0,074	0,070	0,104	0,102	0,082
D	0,093	0,112	0,102	0,098	0,085	0,086	0,073	0,063	0,079	0,076	0,061	0,059	0,086
λ_{max}	4,206	4,128	4,249	4,092	4,033	4,116	4,180	4,204	4,008	4,057	4,263	4,337	4,126
CI	0,069	0,043	0,083	0,031	0,011	0,039	0,060	0,068	0,003	0,019	0,088	0,112	0,042
CR	0,061	0,038	0,074	0,027	0,010	0,035	0,054	0,061	0,002	0,017	0,078	0,100	0,038

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