Selection of the Suitable Location for Solar Power Plant: A Case Study in Türkiye

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Abstract: - Solar energy has gained significant importance in recent years as a reliable and environmentally friendly alternative to conventional energy sources. Its potential to reduce greenhouse gas emissions, mitigate environmental degradation, and decrease dependence on finite fossil fuel resources makes it a critical component of sustainable energy strategies worldwide. Despite its advantages, the deployment of solar power plants involves high initial investment costs, and the selection of an appropriate site is an important factor that directly affects the efficiency, feasibility, and long-term success of such projects. Therefore, a comprehensive and systematic evaluation of potential locations is essential prior to installation. This study aims to determine the most suitable location for a solar power plant in Türkiye by employing an integrated multi-criteria decision-making (MCDM) approach. Specifically, the Analytic Network Process (ANP) is utilized to handle the complex interdependencies among decision criteria, while the the complex proportional assessment (COPRAS) is applied to rank the location alternatives based on their relative closeness to ideal solution. The evaluation criteria are identified through an extensive review of the existing literature as well as expert opinions, ensuring that the model reflects both theoretical insights and practical considerations. The proposed methodology provides a robust decision support framework for policymakers and investors seeking to optimize solar energy site selection in a strategic and informed manner.

Key-Words: - ANP, location selection, MCDM, renewable energy, solar energy, COPRAS

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1 Introduction

Solar energy is a clean, renewable power source harnessed from the sun's rays. It's an increasingly popular form of sustainable energy, due to its potential to reduce carbon footprints and reliance on fossil fuels. The technology to capture and convert solar energy comes in several forms, the most common of which are photovoltaic (PV) panels and solar thermal systems. Photovoltaic panels are the most recognized form of solar technology. PV panels convert sunlight directly into electricity utilizing semiconducting materials. When sunlight hits the panels, it knocks electrons loose from their atoms, generating a flow of electricity. PV panels can be installed on rooftops, in large outdoor solar farms, or in small portable devices. Solar thermal systems use sunlight to heat water or other fluids. The heat is then utilized directly for hot water needs or converted into electrical energy. Solar thermal systems can range from simple passive systems, like solar water heaters, to more complex ones, like concentrated solar power plants.

Today, solar energy is used widely in the world. The aim of this study is to select the most appropriate solar power plant location in Türkiye. Various methodological approaches have been utilized in previous studies to determine suitable locations for solar power plant installations in Türkiye. For instance, Uyan [1] adopted a combination of Geographic Information Systems (GIS) and the Analytic Hierarchy Process (AHP). Özcan et al. [2] integrated the Analytic Network Process (ANP) with the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Yousefi et al. [3] proposed a geographical information system (GIS)-based model incorporating fuzzy Boolean logic. Goh et al. [4] conducted an evaluation based on cost-benefit analysis. Lastly, Khorsidi et al. [5] applied a hybrid approach that merges the fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique with the fuzzy Multi-Objective Optimization by Ratio Analysis (MOORA) method.

In this research, first, ANP is employed to determine the importance of key success factors of solar plant installation. Then, COPRAS method is utilized to find the most appropriate location alternative in Türkiye. The rest of the study is organized as follows. ANP method is briefly illustrated in Section 2. COPRAS method is explained in Section 3. Case study is given in the fourth Section. Finally, conclusions and managerial implications are provided in the last Section.

2 Analytic Network Process

The Analytic Network Process (ANP), introduced by Thomas L. Saaty in 1980 [6], is an advanced form of the Analytic Hierarchy Process (AHP) designed for multi-criteria decision-making (MCDM) applications. Unlike AHP, which assumes a hierarchical structure, ANP allows for more complex interrelationships among decision elements, making it suitable for analyzing systems with inner-dependence among criteria. ANP is particularly useful for determining the relative importance (weights) of decision components within a networked structure.

The methodology involves decomposing a complex decision problem into clusters and elements, and then establishing pairwise comparisons among these elements to assess their relative influence. These comparisons are quantified using a 1-to-9 scale, as originally proposed by Saaty [6], which allows decision-makers to express the intensity of preferences between elements.

The general steps involved in the implementation of ANP are as follows [7]:

Step 1: Define the decision problem and develop a network model that represents the relationships among elements and clusters.

Step 2: Identify the criteria, sub-criteria, and decision alternatives, and determine the dependencies and feedbacks among them.

Step 3: Construct pairwise comparison matrices using the Saaty scale, given in Table 1, to evaluate the relative importance of the elements within and across clusters.

Step 4: The reliability of expert-based pairwise comparisons is evaluated through the Consistency Ratio (CR), calculated for each judgment matrix. A CR value of 0.10 or lower indicates an acceptable level of consistency. If this threshold is exceeded, the comparisons must be re-examined. To compute the CR, the Consistency Index (CI) must first be determined, which is obtained using the following formula [8].

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad (1)$$

The maximum eigenvalue of a square matrix, denoted as λ_{max}, is computed by dividing each element of the priority matrix by the corresponding value in the priority vector. The resulting values are then averaged to obtain λ_{max}.

The appropriate value is selected according to Table 2 showing the values of Random Index (RI) and CR is calculated with the following formula:

$$CR = \frac{CI}{RI} \qquad (2)$$

Table 1. Scale of significance used in pairwise comparisons [6]

Value	**Definition**	**Explanation**
1	Of equal importance	Both criteria are equally important.
3	Moderately more important	Judgments and experiences make one criterion a little more important than another.
5	Strongly or substantially more important	Judgments and experiences make one criterion very important over another.
7	Very strong or demonstrated importance	One criterion is strongly superior to another.
9	Extremely more important	Judgments and experience show that one criterion is extremely superior to another.
2, 4, 6, 8	Intermediate values of the judgment	Intermediate numbers are used if necessary.

Table 2. RI values

Number Of Decision Options (n)	**RI**
1	0.00
2	0.00
3	0.58

4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

Step 5: Create and analyze super matrices.
Step 6: Find the weights of the alternatives.

3 COPRAS Method

The COPRAS (COmplex PRoportional ASsessment) method is introduced by Zavadskas and Kaklauskas [8]. It is a **multi-criteria decision-making (MCDM)** technique used to evaluate and rank a set of alternatives when multiple conflicting criteria are involved. It is particularly useful when decision-makers need to consider both **benefic and cost criteria.** COPRAS evaluates alternatives based on their **proportional contributions** to the ideal solution. It has simple and transparent calculations, moreover it provides a direct ranking of alternatives.

The steps of COPRAS method is given below [9]:

Step 1: Determine the alternatives and the required evaluation criteria. There are *m* alternatives denoted as $A_i = \{A_1, A_2, ..., A_m\}$, which are evaluated under *n* criteria, $C_j = \{C_1, C_2, ..., C_n\}$.

Step 2: Construct the decision matrix that denote the evaluation of alternatives with respect to criteria and the weight matrix of criteria.

Step 3: Normalize the decision matrix. The normalization is computed by dividing each entry by the largest entry in each column.

Step 4: Compute the weighted normalized decision matrix by multiplying the normalized decision matrix with the weight of each criterion.

Step 5: Separate criteria as benefit and cost criteria.

Step 6: Compute the sum of criteria value for benefit-related criteria (P_i).

Step 7: Compute the sum of attributes value for cost-related criteria (R_i).

Step 8: Calculate the relative weight of each alternative as

$$Q_i = P_i + \frac{R_{\min} \sum_i R_i}{R_i \sum_i \frac{R_{\min}}{R_i}} \quad (18)$$

Step 9: Assign the priority of the alternatives (N_i) using Eq. (19) and rank the alternatives.

$$N_i = \frac{Q_i}{Q_{\max}} 100\% \quad (19)$$

4 Case Study

The critical success factors for selecting suitable locations for solar power plant installations are identified as solar radiation, temperature, altitude, slope, proximity to roads, and proximity to transformer stations. These factors are determined based on a comprehensive literature review and expert opinions.

In the subsequent stage, pairwise comparisons among the identified criteria are conducted. The comparisons are guided by the 1-to-9 scale developed by Saaty (referenced in Table 1). The comparison scores are generated through a consensus among multiple experts, ensuring a balanced and representative evaluation. These scores are then compiled into a matrix, referred to as the supermatrix, as previously introduced.

To ensure the consistency of expert judgments, the consistency ratio (CR) was calculated. The resulting CR value is 0.07530, which is within the acceptable threshold of 0.1, indicating that the level of inconsistency in the judgments is tolerable. The supermatrix created before normalization is given in Table 3.

Table 3. The super matrix before normalization

Criteria	Solar Radiation	Heat	Altitude	Slope	Distance To Roads	Distance To Transformer Centers
Solar Radiation	1	4	3	2	6	4
Heat	1/4	1	3	3	5	2
Altitude	1/3	1/3	1	1/3	2	1/3
Slope	1/2	1/3	3	1	6	2
Distance To Roads	1/6	1/5	1/2	1/6	1	1/3
Distance To Transformer Centers	1/4	1/2	3	1/2	3	1
Total	2.50	6.36	13.50	7.00	23.00	9.66

Following this, the initial supermatrix is normalized using specialized software. The normalized matrix is then raised to limiting powers to derive the limit supermatrix, which captures the long-term stable weights of the elements in the network. The final weights of the decision criteria are extracted from the limit supermatrix, and these results are presented in Table 4.

Table 4. Importance of key success factors

Criteria	**Weights**
Solar Radiation	0.38741
Heat	0.22418
Altitude	0.06842
Slope	0.16956
Distance to Roads	0.03825
Distance to Transformer Centers	0.11219

The evaluation of alternatives with respect to criteria are provided in Table 5. It is not desirable that all these criteria be high. Solar radiation, altitude and slope (up to 40 degrees) are benefit criteria and the rest are cost criteria. First the data are normalized by dividing each value by the largest value. Then the weighted normalized matrix is computed considering the weights calculated in Table 4.

Table 5. Evaluation of the alternatives

ALTERNATIVES	CRITERIA					
	Solar Radiation Solaire (kWh/m^2)	Heat (°C)	Altitude (m)	Slope (°)	Distance To Roads (m)	Distance To Transformer Centers (m)
Alternate 1	1718	11.7	1042	28	3500	9500
Alternate 2	1679	9.2	1122	27	2150	6550
Alternate 3	1907	18.5	650	27	300	12100
Alternate 4	1706	19.3	1212	28	640	5745
Alternate 5	1525	12.5	710	28	1275	2650
Weights	0.38741	0.22418	0.06842	0.16956	0.03825	0.11219

By employing the COPRAS method, P_i, R_i, Q_i, and N_i values are obtained as in Table 6, and the alternatives are ranked regarding the *Ni* values.

Table 6. Ranking of the alternatives

Alternatives	P_i	R_i	Q_i	N_i	Rank
A_1	0.58	0.26	0.80	0.91	3
A_2	0.57	0.19	0.88	1.00	1
A_3	0.59	0.33	0.77	0.87	5
A_4	0.58	0.28	0.79	0.90	4
A_5	0.52	0.18	0.84	0.96	2

According to Table 7, Alternative 2 is determined as the most suitable solar plant location alternative.

5 Conclusion

In this research, the integration of ANP and COPRAS methods is employed to determine the most suitable solar plant alternative in Türkiye. The Analytic Network Process (ANP) is utilized to assess the relative significance of the critical success factors involved in selecting optimal locations for solar power plant installations. These factors are identified through a combination of literature analysis and expert evaluations. The ANP results reveal that solar radiation is the most important performance criterion. Subsequently, the COPRAS method is applied to rank the alternatives regarding these criteria.

By employing a hybrid multi-criteria decision-making framework integrating the ANP and COPRAS methods, the study demonstrates a structured and data-driven approach for identifying optimal locations for solar power plant installations in Türkiye.

From a managerial perspective, the use of ANP enables decision-makers to account for the interdependencies among critical site selection factors. COPRAS further assists managers in ranking alternative locations by balancing both benefit and cost-related criteria, thus supporting efficient resource allocation.

This integrated approach allows energy project stakeholders to mitigate risks associated with poor location choices, optimize return on investment, and accelerate progress toward national and international sustainability goals.

While this study presents a robust decision-making framework for solar power plant site selection using an integrated ANP–COPRAS approach, several aspects remain open for future research. The integration of GIS with the MCDM framework could improve the spatial precision of the analysis and provide decision-makers with interactive mapping capabilities. Future studies could also explore the use of alternative or more advanced MCDM methods to handle greater uncertainty and imprecision in expert judgments and data inputs.

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