



Triangular Neutrosophic Multi-Criteria Decision Making AHP Method for Solar Power Site Selection

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Abstract

The depletion of fossil fuel reserves, rising fuel costs, and heightened awareness of ecological problems are just a few of the recent developments that have contributed to a greater reliance on renewable energy alternatives. There is a growing need to evaluate appropriate locations in order to make the most efficient use of renewable energy alternatives. This research looks at the parameters that determine how well-spaced solar farms can be in Egypt. So, the multi-criteria decision-making (MCDM) methodology is used to deal with these criteria. The MCDM is a hybrid with the neutrosophic set to deal with vague information. This paper presented the neutrosophic AHP method to select the best location for solar power (SP). The AHP method is selected to compute the weights of factors in an easy and efficient way. This paper collected the criteria from previous work, then evaluated by the experts. The case study in Egypt is presented to select the best location for SP. The sensitivity analysis is presented to show the rank of locations when changing the weights of factors.

Keywords: Neutrosophic Set; Multi-Criteria Decision Making; Solar Power; Site Selection

1. Introduction

Straight or indirect use of solar or other natural alternatives, as well as the use of resources that deplete quickly, are the basis of renewable energy. Today, renewable sources of power are crucial to the success of our future energy infrastructure. It's much simpler to see why renewable energy is so crucial when we consider problems like the finite amount of fossil fuels available, their uneven distribution over the globe, the unstable governance of places rich in these resources, and the emission of greenhouse gases[1], [2].

The value of rural life is enhanced, economic burdens are lessened, energy independence is increased, dependence on foreign powers is lessened, new local employment is created, and harmful emissions are curbed thanks to the SP's contributions to sustainable growth. Due to their increasing reliance on favorable weather and climate, SP energies now face new problems. Loss of habitat, degraded land, increased noise, and increased visibility are only some of the additional problems that have arisen as a result of this. However, a thorough evaluation of appropriate sites for the construction of SP is clearly necessary to make the most efficient use of commercial supplies and to mitigate the effects of different concerns[3], [4].

The process of deciding where to put SP assets is intricate and challenging. There are several factors to think about while building and operating a plant, including the risks involved and the ecological and social constraints that must be addressed. Locations with abundant alternatives, like solar radiation, are not always the best options for SP installations. Other aspects, such as climate, ecology, and economics, also play an important part in the evaluation of potential sites. A thorough examination of the different aspects influencing the efficiency and effectiveness of renewable energy-based SP is essential prior to making any financial investments in the necessary infrastructure. In the present effort, MCDM-based methodologies are used to determine where in Egypt SP should be installed[5]–[8].

Neutrosophic set (NS) is embraced because of its flexibility in dealing with ambiguity. NS was first proposed by Smarandache, and it was further developed by the fuzzy theory and the fuzzy intuitionistic theory. In fuzzy theory, NS is categorized according to their truthiness, falsity, and indeterminacy rather than their resemblance to triangular values. We used NS and the analytic hierarchy process (AHP) to accomplish our study aims[9]–[11].

In many respects, this work adds to the canon of previous research. This paper introduced the triangular neutrosophic set (TNS) to deal with vague information through the evaluation process. The TNS is a hybrid with the MCDM method because there are many various criteria. The AHP method is used in this paper with the TNS to compute the importance of factors.

2. Related Work

This section shows the previous works in the area of SP. The provided research in [12] examined the technological, financial, and social-environmental viability of potential sites for solar and wind farms in India. A Geographical Information System (GIS) and an MCDM framework are used together to conduct the study. According to the results of their study. Their results showed only 0.91% of the entire area (29,457 km²) is optimal for wind farms, whereas 4.13 % of the studied area (133,874 km²) is ideal for solar plant construction. The authors in [13] conducted a comprehensive analysis of previous research on the topic of PV power plants for utilities. The results of a competent Decision Support system tend to improve thanks to the use of a GIS-based MCDM tool. It makes it simpler for decision-makers and producers to choose locations with the best chance of achieving desired technological efficiency at an acceptable budget and with little environmental effect. The amount of sunlight available is the primary factor in making choices. The main results are urban and reserved land, as well as watercourses and streams, are among the most limiting criteria, land slope and proximity to power lines are also regarded to be among the most essential.

The provided study effort by the authors in [14] conducts a critical analysis of recent advances in Indian solar power in order to identify and assess significant factors that will stimulate more use in the context of India. Given the available research and expert opinions, they were able to narrow down the list of SP enhancers to sixteen. A fuzzy DEMATEL-based technique is used to assess and classify the widely acknowledged major facilitators of solar power development. According to their results, state-level attempts and power sector reforms play a crucial role in fostering India's SP expansion. The authors in [15] conducted a comprehensive literature analysis on the application of artificial intelligence methods such as ANNs, FLs, GAs, and their hybrid frameworks for the design, modeling, tracking of the highest power point, defect detection, and output power/efficiency forecasting for solar photovoltaic systems. Furthermore, we provide a brief overview of the literature on solar radiation forecasting using ANN, FL, GA, and their combined approaches.

To address MCDM concerns in an interval-valued neutrosophic setting, the authors in [16] used an updated version of the WASPAS method, which relies on three innovative techniques. The traditional WASPAS approach is modified in order to accommodate the new features of the expanded technique. Using an objective and subjective combined criterion weight determination approach, the expanded method is able to provide more accurate requirements weight statistics. To show how the suggested technique may be put to use and why it makes sense, they applied it to a case study dealing with the placement of a solar-wind power plant. The authors in [17] discussed how to choose sites for solar power plants using an MCDM approach that combines qualitative and quantitative analysis. Using the Yager t-norm and t-conorm in NS, they developed new operational rules. In addition, a set of new aggregation operators under NE was built using the operational rules discovered by Yager. Furthermore, they developed a technique to deal with the ambiguity inherent in identifying the optimal site for an SP among five alternatives in Pakistan. The superiority and efficiency of the suggested research are shown using a numerical illustration involving the placement issue for solar power plants.

3. Triangular Neutrosophic AHP Method

In this part, we offer a methodical approach to SP placement selection using neutrosophic AHP. In this investigation, three steps were taken. Initially, renewable energy specialists were called and requested to provide a complete list of SP requirements. Second, we compiled a list of the factors considered by specialists when choosing an SP site. Third, we asked for neutrosophic rating preferences from specialists[18], [19]. Using surveys and in-person interviews in this study to collect dataset. Figure 1 shows the proposed methodology.

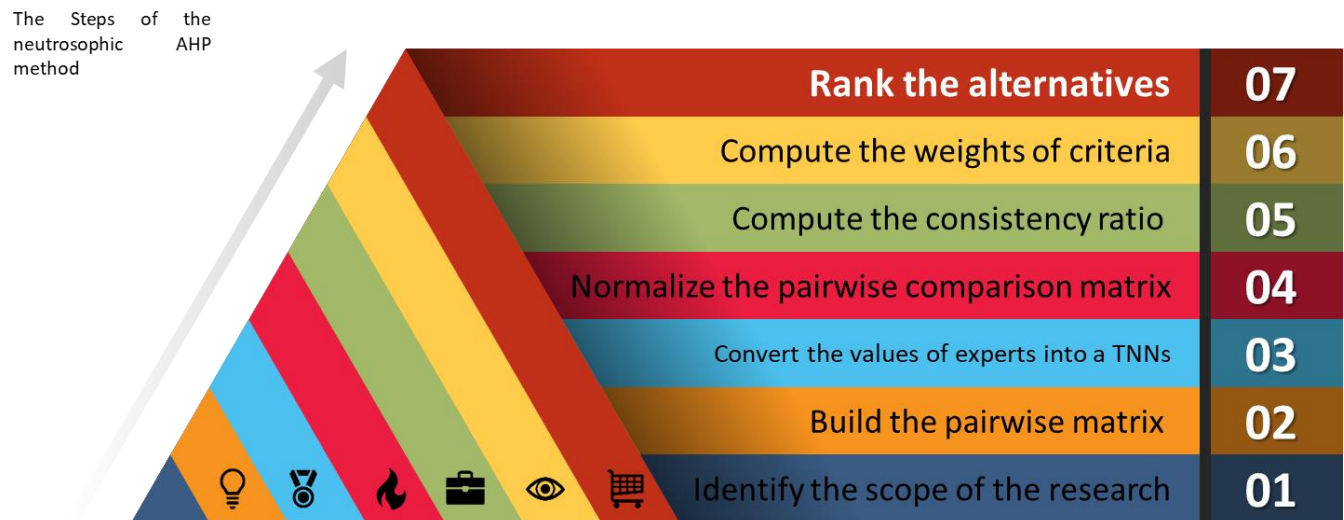


Figure 1: The steps of TNS-AHP.

There are two triangular neutrosophic numbers (TNNs) $X = (x_1, x_2, x_3, x_4, x_5, x_6)$ and $Y = (y_1, y_2, y_3, y_4, y_5, y_6)$, then next the operations in these two numbers as:

$$X \oplus Y = (< x_1 + y_1, x_2 + y_2, x_3 + y_3 >, < x_4 \wedge y_4, x_5 \vee y_5, x_6 \vee y_6 >) \tag{1}$$

$$X \ominus Y = (< x_1 - y_3, x_2 - y_2, y_1 - x_1 >, < x_4 \vee y_4, x_5 \wedge y_5, x_6 \wedge y_6 >) \tag{2}$$

$$X \otimes Y = (< x_1 y_1, x_2 y_2, x_3 y_3 >, < x_4 \wedge y_4, x_5 \vee y_5, x_6 \vee y_6 >) \tag{3}$$

$$vX = \begin{cases} (vx_1, vx_2, vx_3, (x_4, x_5, x_6)) & \text{if } v > 0 \\ ((vx_3, vx_2, vx_1, (x_4, x_5, x_6))) & \text{if } v < 0 \end{cases} \tag{4}$$

Step 1. Identify the scope of the research and the variables to be compared.

Step 2. Build the pairwise matrix

$$C = \begin{pmatrix} 1 & \dots & c_{1n} \\ \vdots & \ddots & \vdots \\ \frac{1}{c_{1n}} & \dots & 1 \end{pmatrix} \tag{5}$$

Step 3. Convert the values of experts into a neutrosophic numbers[20]

Step 4. Normalize the pairwise comparison matrix

Step 5. Compute the consistency ratio (CR)

$$CR = \frac{CI}{RI} \tag{6}$$

$$CI = \frac{(\lambda_{max} - n)}{(n - 1)} \tag{7}$$

Step 6. Compute the weights of criteria

Step 7. Multiply the weights of criteria by the decision matrix

Step 7.1. Build the decision matrix by the criteria and alternatives

Step 7.2. Multiply the weights of criteria by the decision matrix

Step 7.3 Compute the sum of each row

Step 7.4 Rank the alternatives by the highest value of each row

4. Case Study

This section presented a case study in Egypt to select best location in SP. This study collected criteria od SP from previous studies. This study informed the experts to evaluate the criteria and alternatives. Table 1 shows the pairwise comparison between criteria. Table 2 shows the decision matrix between criteria and alternatives. The values in Tables 1 and 2 presented the TNNs. This paper used the scale of neutrosophic and score function from previous study[20].

Table 1: The pairwise comparison matrix.

	SOPC ₁	SOPC ₂	SOPC ₃	SOPC ₄	SOPC ₅	SOPC ₆	SOPC ₇	SOPC ₈	SOPC ₉	SOPC ₁₀
SOPC ₁	1	4.15	5.9	5.9	6.8	2.95	5.9	7.75	6.8	2.95
SOPC ₂	0.24096 4	1	2.95	4.15	5.9	6.8	7.75	6.8	4.15	4.15
SOPC ₃	0.16949 2	0.33898 3	1	7.75	6.8	5.9	4.8	4.15	4.8	4.8
SOPC ₄	0.16949 2	0.24096 4	0.12903 2	1	2.95	2.95	6.8	5.9	4.8	5.9
SOPC ₅	0.14705 9	0.16949 2	0.14705 9	0.33898 3	1	7.75	6.8	6.8	7.75	5.9
SOPC ₆	0.33898 3	0.14705 9	0.16949 2	0.33898 3	0.12903 2	1	4.15	7.75	2.95	7.75
SOPC ₇	0.16949 2	0.12903 2	0.20833 3	0.14705 9	0.14705 9	0.24096 4	1	5.9	2.95	2.95
SOPC ₈	0.12903 2	0.14705 9	0.24096 4	0.16949 2	0.14705 9	0.12903 2	0.16949 2	1	4.15	7.75
SOPC ₉	0.14705 9	0.24096 4	0.20833 3	0.20833 3	0.12903 2	0.33898 3	0.33898 3	0.24096 4	1	7.75
SOPC ₁₀	0.33898 3	0.24096 4	0.20833 3	0.16949 2	0.16949 2	0.12903 2	0.33898 3	0.12903 2	0.12903 2	1

Table 2: The decision matrix by the experts.

	SOPC ₁	SOPC ₂	SOPC ₃	SOPC ₄	SOPC ₅	SOPC ₆	SOPC ₇	SOPC ₈	SOPC ₉	SOPC ₁₀
SOPA ₁	1.1899 9	0.7204 98	0.6268 89	0.5463 54	0.7209 51	0.4871 15	0.2896 27	0.3029 52	0.2210 33	0.1246 06
SOPA ₂	1.1287 91	0.7928 92	0.8315 87	0.3083 66	0.3737 28	0.2363 94	0.2086 13	0.2912 25	0.2364 73	0.1342 79

SOPA ₃	1.8495 85	0.5084 85	0.7864 33	0.8426 82	0.9860 06	0.2449 9	0.2602 59	0.3215 2	0.2039 68	0.1342 79
SOPA ₄	1.5231 87	0.4697 02	0.9745 75	0.7246 14	0.5089 06	0.3510 09	0.1984 86	0.1153 17	0.1348 95	0.1547 62
SOPA ₅	0.8023 93	0.4481 56	0.8729 78	0.7222 99	0.3896 31	0.2883 29	0.1569 66	0.2003 39	0.1935 66	0.1763 83
SOPA ₆	1.6047 87	0.5102 09	1.0761 71	0.6621 08	0.3816 8	0.3080 28	0.1519 02	0.1250 9	0.1612 24	0.1627 28
SOPA ₇	1.2715 89	0.5205 51	1.1213 25	0.5810 8	0.3392 71	0.3008 65	0.1741 81	0.1407 26	0.1170 17	0.1627 28
SOPA ₈	0.8023 93	0.9480 23	1.0234 91	0.4444 92	0.3737 28	0.2328 12	0.1356 99	0.1407 26	0.1267 69	0.1627 28
SOPA ₉	2.1079 82	0.9652 6	0.4440 15	0.2685 47	0.2756 58	0.2077 4	0.1053 19	0.0899 08	0.0845 13	0.1763 83
SOPA ₁₀	1.3939 88	1.0643 72	0.7600 93	0.5810 8	0.4373 41	0.3689 18	0.2288 66	0.2325 89	0.0958 89	0.0671 39

Then, convert the TNNs into a crisp value by used the score function[20]. Then apply the steps of the AHP method. The AHP is used to compute the weights of criteria. The normalization matrix is built by divide each value in comparison matrix by the using of each column. Then obtain the normalization pairwise comparison matrix. Table 3 shows the normalization pairwise comparison matrix.

Table 3: The pairwise comparison matrix.

	SOPC ₁	SOPC ₂	SOPC ₃	SOPC ₄	SOPC ₅	SOPC ₆	SOPC ₇	SOPC ₈	SOPC ₉	SOPC ₁₀
SOPC ₁	0.3508 09	0.6098 89	0.5286 01	0.2924 8	0.2813 21	0.1046 54	0.1550 69	0.1669 54	0.1722 43	0.0579 57
SOPC ₂	0.0845 32	0.1469 61	0.2643	0.2057 27	0.2440 87	0.2412 37	0.2036 93	0.1464 89	0.1051 19	0.0815 32
SOPC ₃	0.0594 59	0.0498 17	0.0895 93	0.3841 89	0.2813 21	0.2093 09	0.1261 58	0.0894 01	0.1215 84	0.0943 03
SOPC ₄	0.0594 59	0.0354 12	0.0115 6	0.0495 73	0.1220 44	0.1046 54	0.1787 24	0.1271	0.1215 84	0.1159 14
SOPC ₅	0.0515 9	0.0249 09	0.0131 75	0.0168 04	0.0413 71	0.2749 4	0.1787 24	0.1464 89	0.1963 07	0.1159 14
SOPC ₆	0.1189 18	0.0216 12	0.0151 85	0.0168 04	0.0053 38	0.0354 76	0.1090 74	0.1669 54	0.0747 23	0.1522 59
SOPC ₇	0.0594 59	0.0189 63	0.0186 65	0.0072 9	0.0060 84	0.0085 48	0.0262 83	0.1271	0.0747 23	0.0579 57
SOPC ₈	0.0452 66	0.0216 12	0.0215 89	0.0084 02	0.0060 84	0.0045 78	0.0044 55	0.0215 42	0.1051 19	0.1522 59
SOPC ₉	0.0515 9	0.0354 12	0.0186 65	0.0103 28	0.0053 38	0.0120 26	0.0089 09	0.0051 91	0.0253 3	0.1522 59
SOPC ₁₀	0.1189 18	0.0354 12	0.0186 65	0.0084 02	0.0070 12	0.0045 78	0.0089 09	0.0027 8	0.0032 68	0.0196 46

Then compute the CR to check the opinions of experts are suitable or not. The CR is less than 0.1, so the opinions of experts are valid. Then compute the weights of factors. Figure 2 shows the weights of criteria.

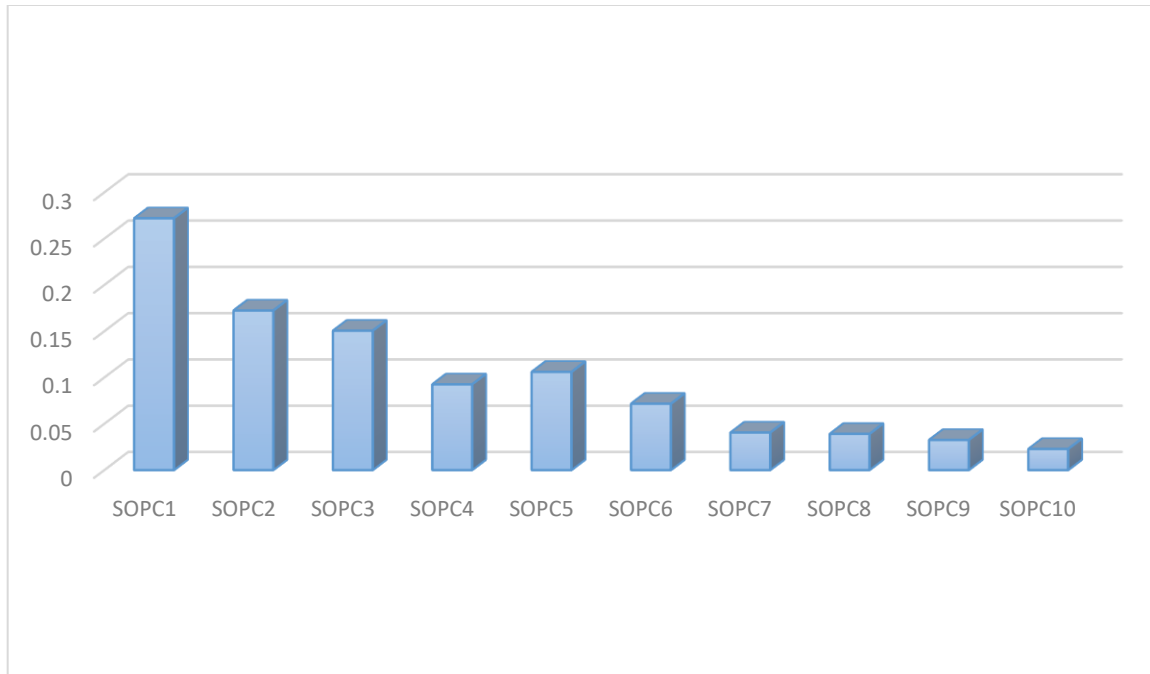


Figure 2: The importance factors of SP.

Then multiply the weights of criteria by the values in decision matrix. Then compute the value of each row. Then rank the location and select best location. Figure 3 shows the rank SP locations.

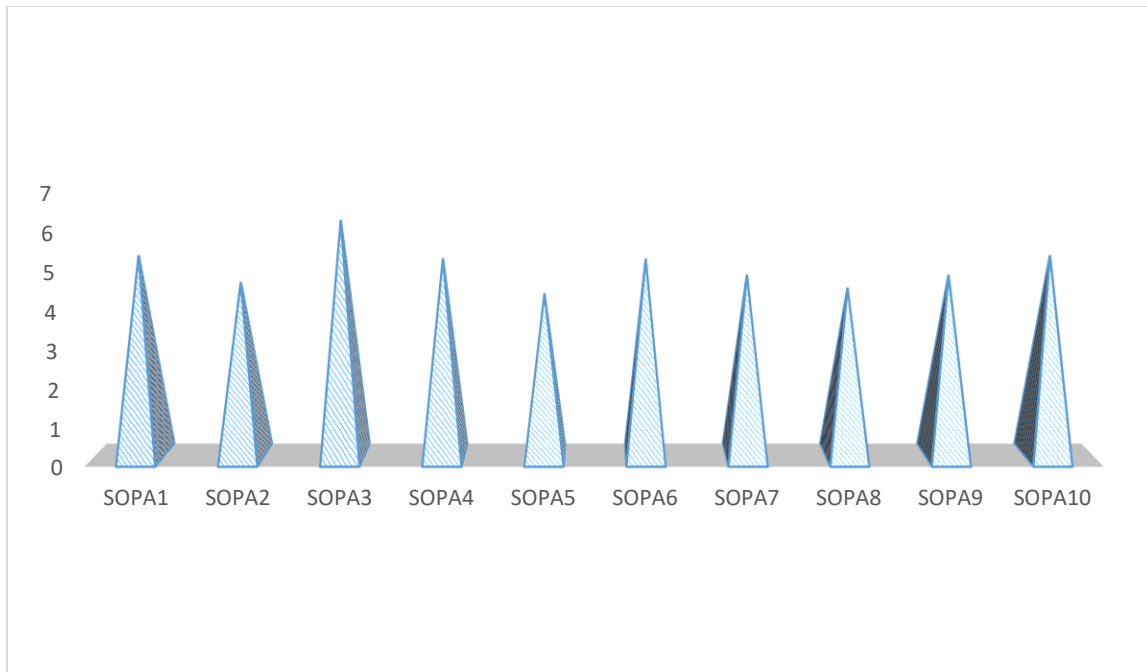


Figure 3. The rank of SP locations.

4.1 Sensitivity analysis

Here, we undertake a sensitivity analysis to further corroborate the validity of the AHP method. This study changed the weights of criteria to show the rank of alternatives. Figure 4 shows the rank of alternatives under different weights of criteria. To check the study's reliability and to learn more about the impact of each variable, a sensitivity analysis was conducted. Figure 4 outlines the sensitivity analysis that was carried out by adjusting the criterion weights for various scenarios.

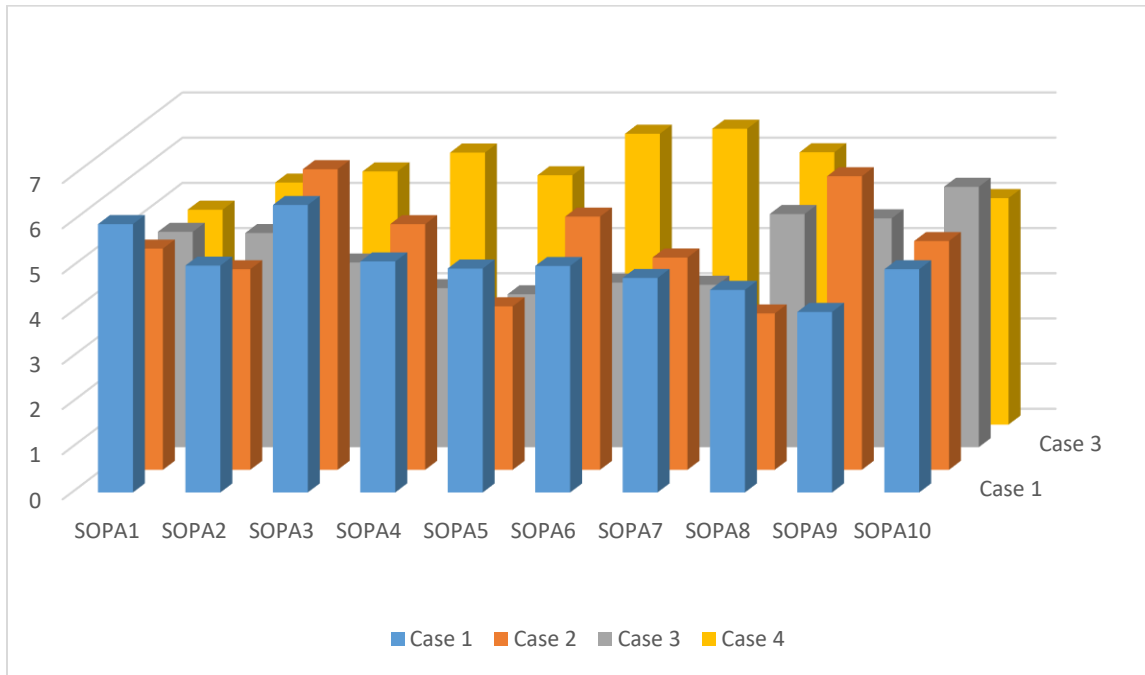


Figure 4: The scenarios in ranking of alternatives.

5. Conclusion

The rapid depletion of traditional energy alternatives has prompted a number of countries to take active initiatives toward optimizing their usage or finding suitable alternatives. In an effort to preserve our planet's precious resources and improve the standard of living, several renewable energy alternatives have been proposed and defended as viable alternatives to traditional energy sources. SP advancements have substantial potential in a country due to factors such as favorable circumstances, energy security, the management of environmental issues, big market share, and so on. But it's not simple to put solar power plans into action. This study evaluates the enabling factors associated with solar power development in an attempt to put them into practice in a practical setting. This study proposes a choice model, elucidates the connections between the enablers, and depicts the causal interactions between them using a causal graph. This study proposed the framework for SP site location. This framework consists of the neutrosophic AHP method. This study used the AHP method to overcome uncertain information. The AHP is used to compute the importance of criteria.

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