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

Abedallah Z. Abualkishik *, Rasha Almajed

American University in the Emirates, Dubai, UAE

Emails: abedallah.abualkishik@aue.ae; rasha.almajed@aue.ae

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].

Doi: https://doi.org/10.54216/IJAACI.020201
Received: June 24, 2022 Accepted: December 23, 2022

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.

Doi: https://doi.org/10.54216/IJAACI.020201
Received: June 24, 2022 Accepted: December 23, 2022

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.

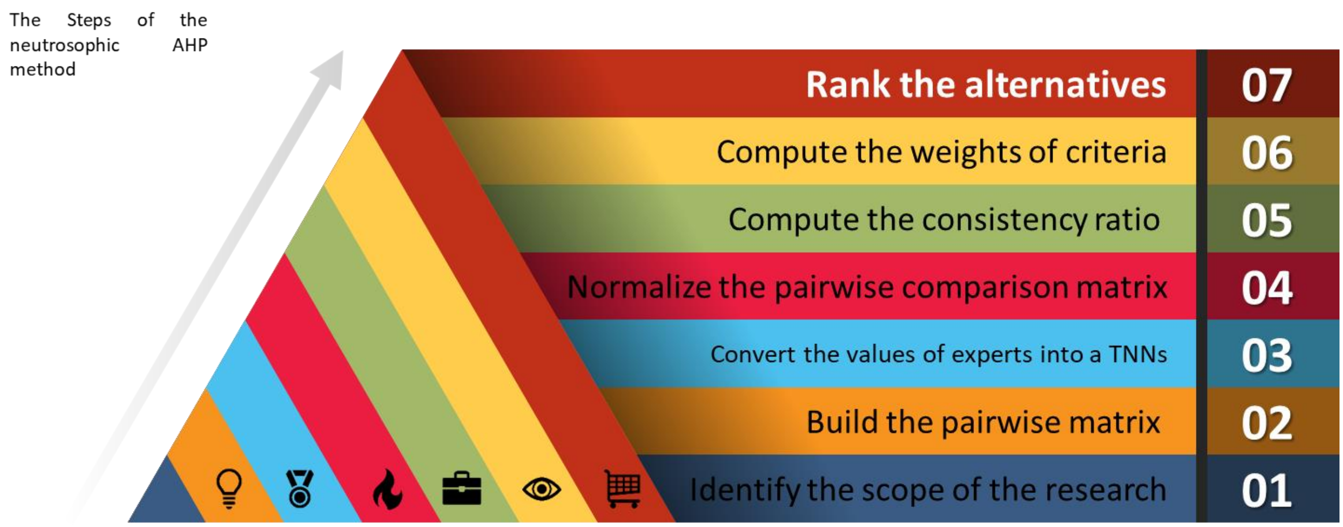

Figure 1: The steps of TNS-AHP.

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:

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

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

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

$$\upsilon X = \begin{cases} (\upsilon x_1, \upsilon x_2, \upsilon x_3, (x_4, x_5, x_6)) if\ \upsilon > 0 \\ \left((\upsilon x_3, \upsilon x_2, \upsilon x_1, (x_4, x_5, x_6))\right) if\ \upsilon < 0 \end{cases} \quad (4)$$

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

Step 2. Build the pairwise matrix

$$C = \begin{pmatrix} 1 & \cdots & c_{1n} \\ \vdots & \ddots & \vdots \\ \frac{1}{c_{1n}} & \cdots & 1 \end{pmatrix} \quad (5)$$

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)

Doi: https://doi.org/10.54216/IJAACI.020201
Received: June 24, 2022 Accepted: December 23, 2022

$$CR = \frac{CI}{RI} \quad (6)$$

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

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
$SOPC_2$	0.240964	1	2.95	4.15	5.9	6.8	7.75	6.8	4.15	4.15
$SOPC_3$	0.169492	0.338983	1	7.75	6.8	5.9	4.8	4.15	4.8	4.8
$SOPC_4$	0.169492	0.240964	0.129032	1	2.95	2.95	6.8	5.9	4.8	5.9
$SOPC_5$	0.147059	0.169492	0.147059	0.338983	1	7.75	6.8	6.8	7.75	5.9
$SOPC_6$	0.338983	0.147059	0.169492	0.338983	0.129032	1	4.15	7.75	2.95	7.75
$SOPC_7$	0.169492	0.129032	0.208333	0.147059	0.147059	0.240964	1	5.9	2.95	2.95
$SOPC_8$	0.129032	0.147059	0.240964	0.169492	0.147059	0.129032	0.169492	1	4.15	7.75
$SOPC_9$	0.147059	0.240964	0.208333	0.208333	0.129032	0.338983	0.338983	0.240964	1	7.75
$SOPC_{10}$	0.338983	0.240964	0.208333	0.169492	0.169492	0.129032	0.338983	0.129032	0.129032	1

Table 2: The decision matrix by the experts.

	$SOPC_1$	$SOPC_2$	$SOPC_3$	$SOPC_4$	$SOPC_5$	$SOPC_6$	$SOPC_7$	$SOPC_8$	$SOPC_9$	$SOPC_{10}$
$SOPA_1$	1.18999	0.720498	0.626889	0.546354	0.720951	0.487115	0.289627	0.302952	0.221033	0.124606
$SOPA_2$	1.128791	0.792892	0.831587	0.308366	0.373728	0.236394	0.208613	0.291225	0.236473	0.134279

Doi: https://doi.org/10.54216/IJAACI.020201
Received: June 24, 2022 Accepted: December 23, 2022

SOPA$_3$	1.849585	0.508485	0.786433	0.842682	0.986006	0.24499	0.260259	0.32152	0.203968	0.134279
SOPA$_4$	1.523187	0.469702	0.974575	0.724614	0.508906	0.351009	0.198486	0.115317	0.134895	0.154762
SOPA$_5$	0.802393	0.448156	0.872978	0.722299	0.389631	0.288329	0.156966	0.200339	0.193566	0.176383
SOPA$_6$	1.604787	0.510209	1.076171	0.662108	0.38168	0.308028	0.151902	0.12509	0.161224	0.162728
SOPA$_7$	1.271589	0.520551	1.121325	0.58108	0.339271	0.300865	0.174181	0.140726	0.117017	0.162728
SOPA$_8$	0.802393	0.948023	1.023491	0.444492	0.373728	0.232812	0.135699	0.140726	0.126769	0.162728
SOPA$_9$	2.107982	0.96526	0.444015	0.268547	0.275658	0.20774	0.105319	0.089908	0.084513	0.176383
SOPA$_{10}$	1.393988	1.064372	0.760093	0.58108	0.437341	0.368918	0.228866	0.232589	0.095889	0.067139

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$_1$	0.350809	0.609889	0.528601	0.29248	0.281321	0.104654	0.155069	0.166954	0.172243	0.057957
SOPC$_2$	0.084532	0.146961	0.2643	0.205727	0.244087	0.241237	0.203693	0.146489	0.105119	0.081532
SOPC$_3$	0.059459	0.049817	0.089593	0.384189	0.281321	0.209309	0.126158	0.089401	0.121584	0.094303
SOPC$_4$	0.059459	0.035412	0.01156	0.049573	0.122044	0.104654	0.178724	0.1271	0.121584	0.115914
SOPC$_5$	0.05159	0.024909	0.013175	0.016804	0.041371	0.27494	0.178724	0.146489	0.196307	0.115914
SOPC$_6$	0.118918	0.021612	0.015185	0.016804	0.005338	0.035476	0.109074	0.166954	0.074723	0.152259
SOPC$_7$	0.059459	0.018963	0.018665	0.00729	0.006084	0.008548	0.026283	0.1271	0.074723	0.057957
SOPC$_8$	0.045266	0.021612	0.021589	0.008402	0.006084	0.004578	0.004455	0.021542	0.105119	0.152259
SOPC$_9$	0.05159	0.035412	0.018665	0.010328	0.005338	0.012026	0.008909	0.005191	0.02533	0.152259
SOPC$_{10}$	0.118918	0.035412	0.018665	0.008402	0.007012	0.004578	0.008909	0.00278	0.003268	0.019646

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.

Doi: https://doi.org/10.54216/IJAACI.020201
Received: June 24, 2022 Accepted: December 23, 2022

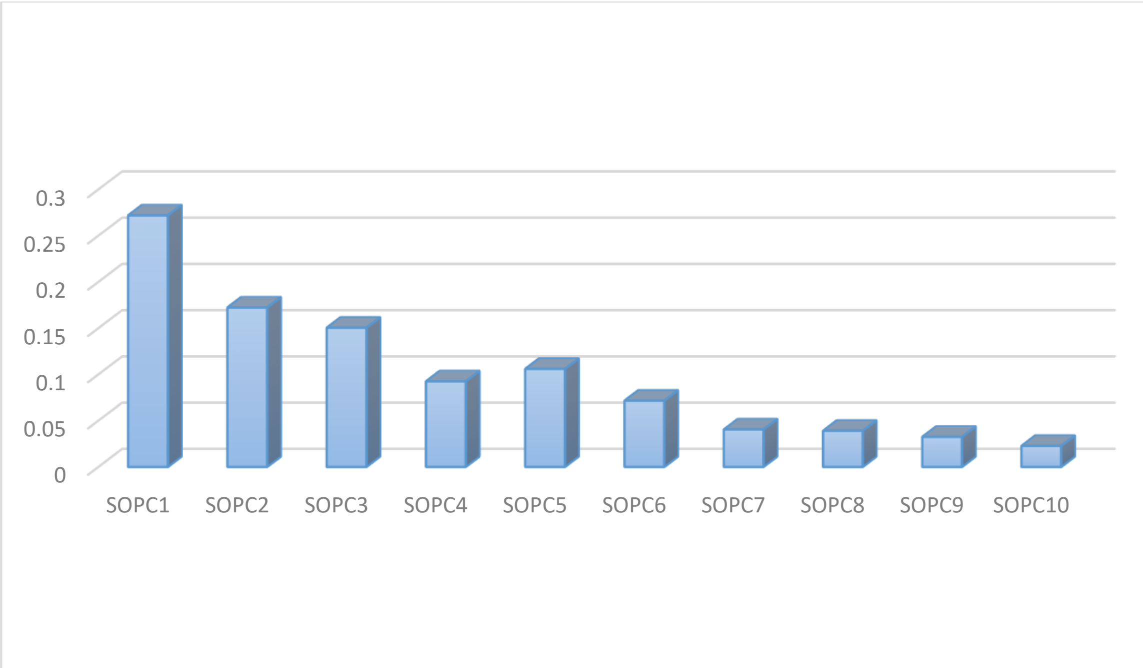

Figure 2: The importance factors of SP.

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.

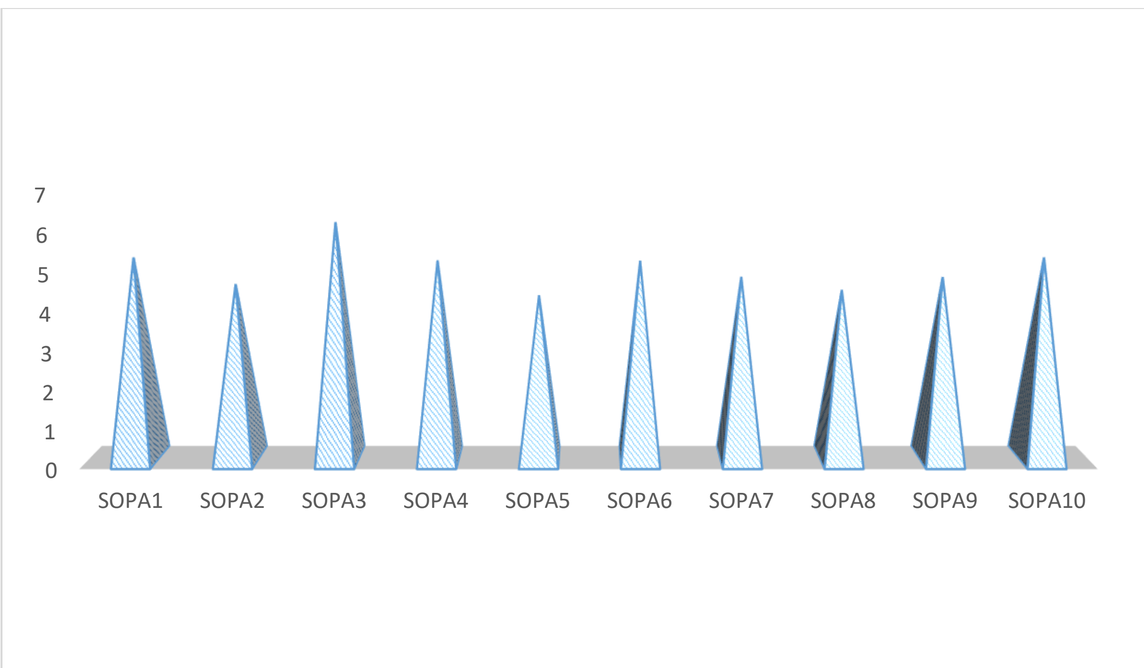

Figure 3. The rank of SP locations.

4.1 Sensitivity analysis

Doi: https://doi.org/10.54216/IJAACI.020201
Received: June 24, 2022 Accepted: December 23, 2022

Here, we undertake a sensitivity analysis to further corroborate the validity of the AHP method. This study changed the weights of criteria to shows 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.

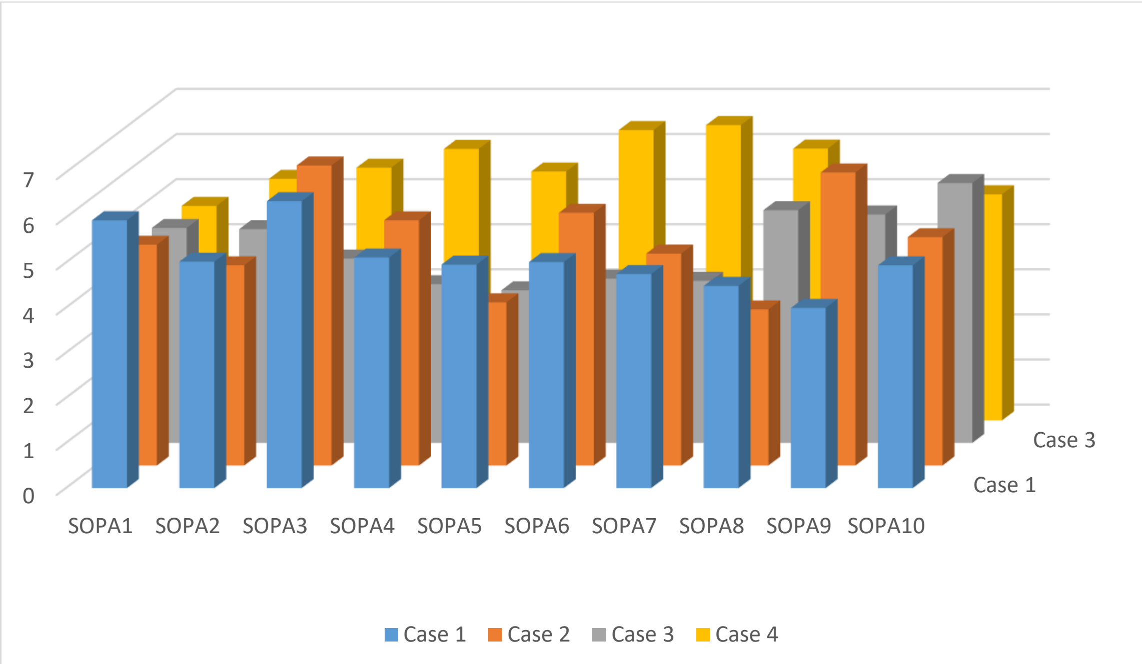

Figure 4: The scenarios in ranking of alternatives.

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.

References

[1] Y. Simsek, D. Watts, and R. Escobar, “Sustainability evaluation of concentrated solar power (CSP) projects under clean development mechanism (CDM) by using multi criteria decision method (MCDM),” *Renew. Sustain. Energy Rev.*, vol. 93, pp. 421–438, 2018.

[2] C.-N. Wang, V. T. Nguyen, H. T. N. Thai, and D. H. Duong, “Multi-criteria decision making (MCDM) approaches for solar power plant location selection in Viet Nam,” *Energies*, vol. 11, no. 6, p. 1504, 2018.

Doi: https://doi.org/10.54216/IJAACI.020201
Received: June 24, 2022 Accepted: December 23, 2022

[3] R. Ghasempour, M. A. Nazari, M. Ebrahimi, M. H. Ahmadi, and H. Hadiyanto, "Multi-Criteria Decision Making (MCDM) Approach for Selecting Solar Plants Site and Technology: A Review.," *Int. J. Renew. Energy Dev.*, vol. 8, no. 1, 2019.

[4] M. B. Alqaderi, W. Emar, and O. A. Saraereh, "Concentrated solar power site suitability using GIS-MCDM technique taken UAE as a case study," *Int. J. Adv. Comput. Sci. Appl.*, vol. 9, no. 4, 2018.

[5] M. Jahangiri, A. A. Shamsabadi, A. Mostafaeipour, M. Rezaei, Y. Yousefi, and L. M. Pomares, "Using fuzzy MCDM technique to find the best location in Qatar for exploiting wind and solar energy to generate hydrogen and electricity," *Int. J. Hydrogen Energy*, vol. 45, no. 27, pp. 13862–13875, 2020.

[6] T.-C. Wang and S.-Y. Tsai, "Solar panel supplier selection for the photovoltaic system design by using fuzzy multi-criteria decision making (MCDM) approaches," *Energies*, vol. 11, no. 8, p. 1989, 2018.

[7] S. Ishfaq, S. Ali, and Y. Ali, "Selection of optimum renewable energy source for energy sector in Pakistan by using MCDM approach," *Process Integr. Optim. Sustain.*, vol. 2, pp. 61–71, 2018.

[8] Y. Wu, C. Xu, and T. Zhang, "Evaluation of renewable power sources using a fuzzy MCDM based on cumulative prospect theory: A case in China," *Energy*, vol. 147, pp. 1227–1239, 2018.

[9] M. Mullai and R. Surya, "Neutrosophic inventory backorder problem using triangular neutrosophic numbers," *Neutrosophic Sets Syst.*, vol. 31, pp. 148–155, 2020.

[10] S. A. Edalatpanah, "Data envelopment analysis based on triangular neutrosophic numbers," *CAAI Trans. Intell. Technol.*, vol. 5, no. 2, pp. 94–98, 2020.

[11] S. Broumi, D. Nagarajan, A. Bakali, M. Talea, F. Smarandache, and M. Lathamaheswari, "The shortest path problem in interval valued trapezoidal and triangular neutrosophic environment," *Complex Intell. Syst.*, vol. 5, pp. 391–402, 2019.

[12] S. Luthra, K. Govindan, R. K. Kharb, and S. K. Mangla, "Evaluating the enablers in solar power developments in the current scenario using fuzzy DEMATEL: An Indian perspective," *Renew. Sustain. Energy Rev.*, vol. 63, pp. 379–397, 2016.

[13] K. S. Garud, S. Jayaraj, and M. Lee, "A review on modeling of solar photovoltaic systems using artificial neural networks, fuzzy logic, genetic algorithm and hybrid models," *Int. J. Energy Res.*, vol. 45, no. 1, pp. 6–35, 2021.

[14] R. Malemnganbi and B. A. Shimray, "Solar power plant site selection: a systematic literature review on MCDM techniques used," *Electron. Syst. Intell. Comput. Proc. ESIC 2020*, pp. 37–48, 2020.

[15] S. K. Saraswat, A. K. Digalwar, S. S. Yadav, and G. Kumar, "MCDM and GIS based modelling technique for assessment of solar and wind farm locations in India," *Renew. Energy*, vol. 169, pp. 865–884, 2021.

[16] R. Nie, J. Wang, and H. Zhang, "Solving solar-wind power station location problem using an extended weighted aggregated sum product assessment (WASPAS) technique with interval neutrosophic sets," *Symmetry (Basel).*, vol. 9, no. 7, p. 106, 2017.

[17] S. Khan, S. Abdullah, S. Ashraf, R. Chinram, and S. Baupradist, "Decision Support Technique Based on Neutrosophic Yager Aggregation Operators: Application in Solar Power Plant Locations—Case Study of Bahawalpur, Pakistan," *Math. Probl. Eng.*, vol. 2020, pp. 1–21, 2020.

[18] A. Chakraborty, S. P. Mondal, A. Ahmadian, N. Senu, S. Alam, and S. Salahshour, "Different forms of triangular neutrosophic numbers, de-neutrosophication techniques, and their applications," *Symmetry (Basel).*, vol. 10, no. 8, p. 327, 2018.

[19] S. A. Edalatpanah, "A direct model for triangular neutrosophic linear programming," *Int. J. neutrosophic Sci.*, vol. 1, no. 1, pp. 19–28, 2020.

[20] M. Junaid, Y. Xue, M. W. Syed, J. Z. Li, and M. Ziaullah, "A neutrosophic ahp and topsis framework for supply chain risk assessment in automotive industry of Pakistan," *Sustainability*, vol. 12, no. 1, p. 154, 2019.

Doi: https://doi.org/10.54216/IJAACI.020201
Received: June 24, 2022 Accepted: December 23, 2022