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Single Valued Neutrosophic Sets Approach for Assessment Wind Power Plant

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Abstract

Full exploitation of offshore wind resources still needs to be completed despite their significant potential to reduce the impacts of climate change via the production of renewable power. Planning strategies that include wind resources, safety, economic, social, and government impacts are essential for advancing offshore wind generation projects. This study aims to evaluate the criteria for wind power plants and select the best turbine. This process has various conflict criteria, so the multi-criteria decision-making (MCDM) methodology deals with multiple criteria. The ARAS method is an MCDM method used to rank the alternatives. The ARAS method uses the single-valued neutrosophic set to deal with uncertain information. We gathered eleven criteria and fifteen alternatives. The results show the turbine resource is the best and the economic criterion is the worst. The sensitivity analysis is conducted to ensure the proposed model's results and show the strength of the proposed method. The results show the proposed model is suitable for selecting the best wind power plant.

Keywords: Power Plant; Wind; Assessment Problem; MCDM; Neutrosophic Sets; ARAS Method.

1. Introduction

Greenhouse gas (GHG) emissions from the burning of fossil fuels have triggered a worldwide climate disaster. Even if fossil fuels continue to be the dominant energy source in 2021, there has been a boom in energy demand in recent years owing to technological advancements and population expansion[1]–[3]. To achieve the objectives of the Paris Agreement and slow global warming, it is critical to decrease dependency on fossil fuels, particularly in the energy sector. Governments are encouraging the integration of renewable energy sources (RES) to promote sustainability, and the transition to RES and nuclear energy efficiently decreases greenhouse gas emissions in power production[4], [5].

The wind industry, which includes onshore and offshore wind farms (WF), is a promising option for generating electricity from renewable sources. There was a total of 906 GW built in the previous three years (2020-2022), 64 GW

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of which came from offshore wind farms (OWF)[6]–[8]. Despite difficulties associated with operating at sea, offshore wind energy capacity has increased by 1180% during the previous decade. Offshore wind energy is not limited by land and has fewer environmental problems than onshore WF. In addition, OWF may help spread low-GHG power to outlying regions[9], [10].

The choice of a wind power plant is an example of a multi-criteria decision-making (MCDM) dilemma due to the large number of parameters for consideration. Here, MCDM techniques may be used for further investigation of the issue at hand[11], [12].

One of the most consequential and pervasive activities concerning actual uses is MCDM, and this has been the case for some decades now. Several attempts at evaluating the RESs using various MCDM methodologies have been made in the published literature. Traditional methods of decision-making are not effective when dealing with the kind of unclear data often encountered during energy planning. With this in mind, the concept of the fuzzy set (FS) has sparked the interest of scholars all over the world due to its adaptability and efficacy in dealing with scenarios where the available information is insufficient or ambiguous[13]–[15].

However, FS and IFS ideas can only handle partial and uncertain data, not the inconsistent and indeterminate data seen in real-world scenarios. Smarandache conceived of the neutrosophic set (NS) as a means of more precisely managing such data. Part of the field of study known as neutrosophy, NS is a robust universal formal framework that philosophically reduces the aforementioned sets by focusing on their origins, natures, and scopes in relation to various ideational spectra. Neutrosophy, which means "knowledge of neutral thought," is a key sign of the main difference between FSs and IFSs and their respective logics, and the name itself defines this information. NS is characterized by three separate membership functions which explain the function of truth, indeterminacy, and falsity. Each of these three functions takes on values in the out-of-the-ordinary range of [0-, 1+][16]–[18].

As a result, the NS has widespread support for making plans based on uncertain and contradictory data. However, an NS's membership functions have a co-domain that is either a true standard subset or a nonstandard subset of [0, 1+][19], [20].

As a result, from a scientific point of view, it is difficult to implement the NSs in real-world scenarios. Therefore, the theory of single-valued neutrosophic set (SVNS) has been developed by Wang et al. with various novel and pioneering qualities for improved applications in practical scientific and industrial sectors[21], [22].

An integrated MCDM strategy for handling the multi-criteria wind power plant assessment issue in a single-valued neutrosophic setting is developed in this paper, which draws inspiration from the idea of single-valued network services (SVNSs). When confronted with an MCDM challenge, decision-makers (DMs) must evaluate the relative importance of each criterion and rank the available solutions in order of importance. Because of the complexity of decision environments and DMs' insufficient experience with them, information regarding the criterion weights is sometimes entirely unknown[23]–[25].

The key contributions of this study are as follows:

The proposed MCDM method with an ARAS method integrated with the single-valued neutrosophic set to evaluate the wind power plant.

The weights of criteria are computed to show the importance of wind criteria for key considerations of decision-makers and experts.

The neutrosophic sets were used to deal with uncertain information in this study.

The application is applied to show the results of the proposed model and show the best wind power plant with a specific criterion.

The sensitivity analysis is performed to show the robustness of the proposed model.

2. Neutrosophic Approach

Smarandache created the first NS model. Since the DMs aren't always well-versed in all the facets of the decision-making process and all the functions are autonomous under NS theory, each element has a degree of indeterminacy beyond the membership and non-membership degrees.

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Because it is based on a philosophical idea, NS is difficult to digest in technical applications and to implement in real-world situations. Initiating the concept of SVNSs, Wang et al. defined Z as a universal set consisting of a finite set of items that are taken into account as subjective (Likert scale) rating values throughout the decision-making process. The membership, non-membership, and indeterminacy grades are connected with each of these rating factors inside the universe of choice data used in decision-making.

Let $u = (u_1, u_2, u_3), and\ v = (v_1, v_2, v_3)$ two single valued neutrosophic numbers, where u_1, u_2, u_3 refer to the truth, indeterminacy, and falsity degrees, and some operations of single-valued neutrosophic numbers are:

$$u^c = (u_3, 1 - u_2, u_1) \tag{1}$$

$$u \cup v = (\max\{u_1, v_1\}, \min\{u_2, v_2\}, \min\{u_3, v_3\}) \tag{2}$$

$$u \cap v = (\min\{u_1, v_1\}, \max\{u_2, v_2\}, \max\{u_3, v_3\}) \tag{3}$$

$$u \oplus v = (u_1 + v_1 - u_1v_1, u_2v_2, u_3v_3) \tag{4}$$

$$u \otimes v = (u_1v_1, u_2+v_2-u_2v_2, u_3+v_3-u_3v_3) \tag{5}$$

$$\beta u = \left(1 - (1 - u_1)^\beta, u_2^\beta, u_3^\beta\right) \tag{6}$$

$$u^\beta = \left(u_1^\beta, 1 - (1 - u_2)^\beta, 1 - (1 - u_3)^\beta\right) \tag{7}$$

We can compute the score function as:

$$S(u) = \frac{2+u_1-u_2-u_3}{3} \tag{8}$$

Figure 1: The stages of the proposed method.

Ranking and prioritization using the Additive Ratio Assessment (ARAS) was first proposed in 2010 by Zavadsakas et al. One of the best multi-criteria decision-making procedures may be used to determine the best option based on several factors. The ARAS technique prioritizes solutions by minimizing their distance to positive elements and increasing their distance from negative ones. The stages of the ARAS approach are shown in Figure 1 and as follows, in order:

Stage 1. Build the initial Matrix

We gather the criteria and alternatives of wind evaluation in a power plant. Then let the experts evaluate the criteria and alternatives by building the initial decision matrix by their opinions with the terms of single value neutrosophic sets. We used the single-valued neutrosophic numbers in this study to assess the criteria and alternatives.

$$A_{ij} = \begin{pmatrix} A_{11} & \cdots & A_{1n} \\ \vdots & \ddots & \vdots \\ A_{m1} & \cdots & A_{mn} \end{pmatrix} \tag{9}$$

Where $i = 1,2, \dots . m; and\ j = 1,2, \dots n$

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Stage 2. Normalize the initial decision matrix

The initial decision matrix is normalized based on positive and cost criteria as:

$$A_{ij}^{*} = \frac{A_{ij}}{\sum_{i=0}^{m} A_{ij}} \tag{10}$$

$$A_{ij} = \frac{1}{A_{ij}^{*}} \tag{11}$$

Stage 3. Build the normal decision matrix

The weights of the criteria are computed by the average method. Then the weights of the criteria are multiplied by the normalization matrix to compute the normal decision matrix.

$$N_{ij} = A_{ij}^{*} * w_j \tag{12}$$

Stage 4. Compute the utility values

The utility value by the next equation with the desirability function.

$$F_i = \sum_{j=1}^{n} N_{ij} \tag{13}$$

Stage 5. Compute the utility degree

$$U_i = \frac{F_i}{F_0} \tag{14}$$

3. Results

In this section, we introduce the results of the single-valued neutrosophic ARAS method. We collected eleven criteria and fifteen winds to select the best one. The criteria are collected from the previous research. The criteria of this study are organized as:

1. Safety: Safety issues, such as turbine failure, fire danger, and construction and maintenance personnel, must be identified and mitigated.
2. Economic: Review of all relevant expenditures, including initial outlay, ongoing upkeep, and the possibility of profit from power sales.
3. Wind Resource: Assessing the site's potential wind resources by measuring wind speed, direction, and turbulence. Wind resource data gathering and analysis for maximum efficiency in producing electricity.
4. Social acceptance: Involvement with neighborhood groups and individuals to answer questions, disseminate data, and foster goodwill.
5. Environmental Effects: Evaluation of the ecological effects connected with the building, operation, and dismantling of the wind power project.
6. Site selection: Identification of ideal places with favorable wind conditions, avoiding barriers and minimizing turbulence.
7. Wind technology and design: Wind resource evaluation and site-specific factors will inform the choice of wind turbine type and design. The power curve features, hub height, rotor diameter, and turbine capacity are all taken into account.
8. Power Capacity: Evaluation of the Wind Power Plant's Capacity and Capacity to Generate Electricity
9. Compliance: Observance of all relevant laws, ordinances, permits, and licenses on a regional, state, and federal level.
10. Operation and maintenance: Analysis of inspection, repair, and service needs for turbines, as well as other operating necessities
11. Grid infrastructure: To ensure the wind plant's electricity is seamlessly integrated into the grid, it is important to assess the grid infrastructure and connection needs.

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Stage 1. Eq. (9) is used to build the initial decision matrix between eleven criteria and fifteen alternatives. The experts used the single-valued neutrosophic number to assess the criteria and alternatives. Then Eq. (8) is used to obtain the crisp values.

Stage 2. We normalize the initial decision matrix for positive and cost criteria by using Eqs. (10 and 11). All criteria are positive except the economic criterion is cost. The normalization matrix is shown in Table 1.

Table 1: The normalization decision matrix.

	PPC$_1$	**PPC$_2$**	**PPC$_3$**	**PPC$_4$**	**PPC$_5$**	**PPC$_6$**	**PPC$_7$**	**PPC$_8$**	**PPC$_9$**	**PPC$_{10}$**	**PPC$_{11}$**
PPT$_1$	0.032439	0.070745	0.113765	0.050768	0.088341	0.066985	0.051871	0.043973	0.066614	0.088029	0.106951
PPT$_2$	0.11711	0.049091	0.082545	0.032826	0.118719	0.081401	0.107771	0.077644	0.029888	0.066375	0.077828
PPT$_3$	0.085221	0.031741	0.100757	0.103067	0.016999	0.109392	0.093871	0.104344	0.1079	0.046032	0.032135
PPT$_4$	0.035188	0.099661	0.073321	0.035607	0.050445	0.015664	0.045954	0.014941	0.078519	0.029763	0.045441
PPT$_5$	0.049758	0.083387	0.030274	0.050768	0.032617	0.032601	0.029712	0.063894	0.032421	0.093452	0.029738
PPT$_6$	0.08786	0.034431	0.04281	0.057348	0.10241	0.0461	0.093292	0.07677	0.045845	0.066451	0.066028
PPT$_7$	0.118072	0.11459	0.100757	0.087906	0.056941	0.122649	0.121116	0.077644	0.080418	0.066337	0.080238
PPT$_8$	0.016907	0.083387	0.073321	0.088907	0.088341	0.066985	0.045954	0.104344	0.088397	0.124477	0.107829
PPT$_9$	0.11711	0.034431	0.030274	0.11948	0.118719	0.081401	0.029712	0.014941	0.1079	0.046032	0.045818
PPT$_{10}$	0.085221	0.049091	0.04281	0.050768	0.016999	0.109392	0.093292	0.09001	0.078519	0.029763	0.029625
PPT$_{11}$	0.035188	0.031741	0.062204	0.032826	0.088341	0.015664	0.017122	0.07762	0.032421	0.093452	0.093017
PPT$_{12}$	0.049758	0.099661	0.100757	0.103067	0.118719	0.080866	0.080475	0.103494	0.045845	0.080588	0.080238
PPT$_{13}$	0.085221	0.085969	0.073321	0.050768	0.016999	0.046482	0.108148	0.075312	0.08095	0.046032	0.107829
PPT$_{14}$	0.035188	0.115532	0.030274	0.032826	0.035381	0.030054	0.015486	0.031097	0.108787	0.029763	0.01544
PPT$_{15}$	0.049758	0.016543	0.04281	0.103067	0.05003	0.094365	0.066223	0.043973	0.015577	0.093452	0.081845

Stage 3. We build the normal decision matrix by using Eq. (12) as shown in Table 2. Before that, we compute the weights of criteria by the average method as shown in Figure 2. From the results of weights, we observe the wind resource is the highest weight and the economic and social criteria are the lowest weights.

Table 2: The normal decision matrix.

	PPC$_1$	**PPC$_2$**	**PPC$_3$**	**PPC$_4$**	**PPC$_5$**	**PPC$_6$**	**PPC$_7$**	**PPC$_8$**	**PPC$_9$**	**PPC$_{10}$**	**PPC$_{11}$**
PPT$_1$	0.002895	0.004166	0.014931	0.00356	0.007483	0.007084	0.005457	0.004274	0.005617	0.00731	0.009656
PPT$_2$	0.010451	0.002891	0.010834	0.002302	0.010056	0.008609	0.011338	0.007546	0.00252	0.005512	0.007027
PPT$_3$	0.007605	0.001869	0.013224	0.007227	0.00144	0.011569	0.009876	0.010141	0.009099	0.003822	0.002901
PPT$_4$	0.00314	0.005868	0.009623	0.002497	0.004273	0.001657	0.004835	0.001452	0.006621	0.002471	0.004103

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PPT 5	0.00444	0.00491	0.003973	0.00356	0.002763	0.003448	0.003126	0.00621	0.002734	0.00776	0.002685
PPT 6	0.007841	0.002027	0.005619	0.004021	0.008675	0.004876	0.009815	0.007461	0.003866	0.005518	0.005961
PPT 7	0.010537	0.006747	0.013224	0.006164	0.004823	0.012971	0.012742	0.007546	0.006782	0.005508	0.007244
PPT 8	0.001509	0.00491	0.009623	0.006234	0.007483	0.007084	0.004835	0.010141	0.007454	0.010336	0.009735
PPT 9	0.010451	0.002027	0.003973	0.008378	0.010056	0.008609	0.003126	0.001452	0.009099	0.003822	0.004137
PPT 10	0.007605	0.002891	0.005619	0.00356	0.00144	0.011569	0.009815	0.008748	0.006621	0.002471	0.002675
PPT 11	0.00314	0.001869	0.008164	0.002302	0.007483	0.001657	0.001801	0.007544	0.002734	0.00776	0.008398
PPT 12	0.00444	0.005868	0.013224	0.007227	0.010056	0.008552	0.008467	0.010059	0.003866	0.006692	0.007244
PPT 13	0.007605	0.005062	0.009623	0.00356	0.00144	0.004916	0.011378	0.00732	0.006826	0.003822	0.009735
PPT 14	0.00314	0.006803	0.003973	0.002302	0.002997	0.003179	0.001629	0.003022	0.009174	0.002471	0.001394
PPT 15	0.00444	0.000974	0.005619	0.007227	0.004238	0.00998	0.006967	0.004274	0.001314	0.00776	0.007389

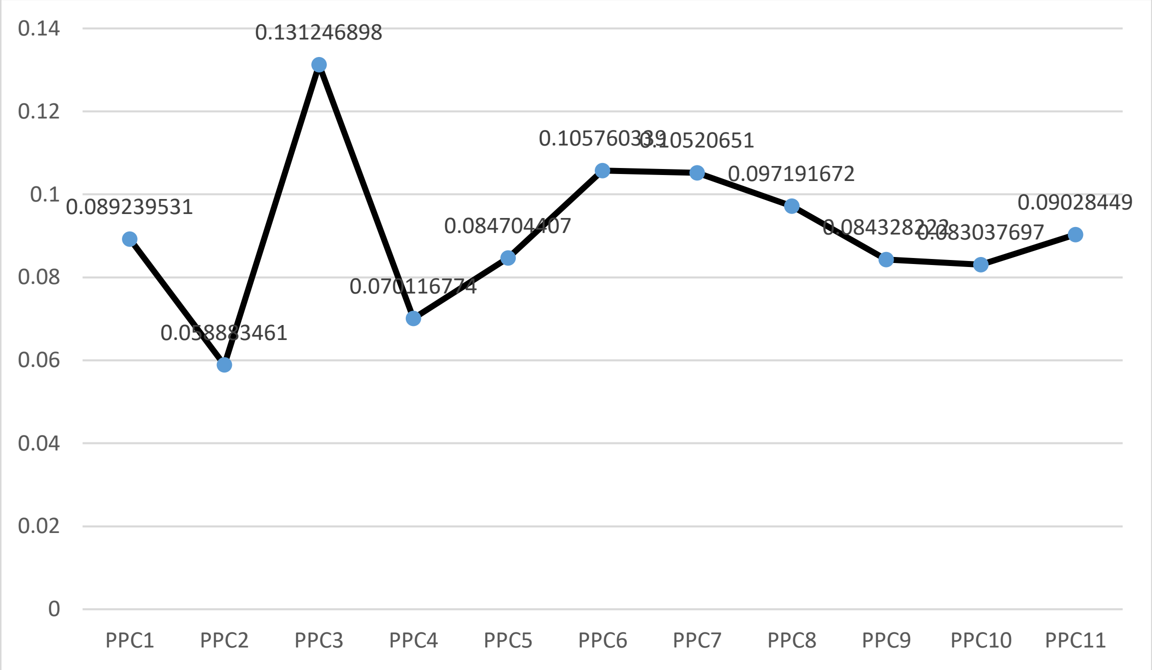

Figure 2: The weights of eleven criteria.

Stage 4. Then we compute the utility values by using Eq. (13).

Stage 5. Then we compute the utility degree by using Eq. (14) as shown in Figure 3. Then rank the alternatives based on the largest value of the utility degree. We show the alternative 8 is the best and the alternative 9 is the worst.

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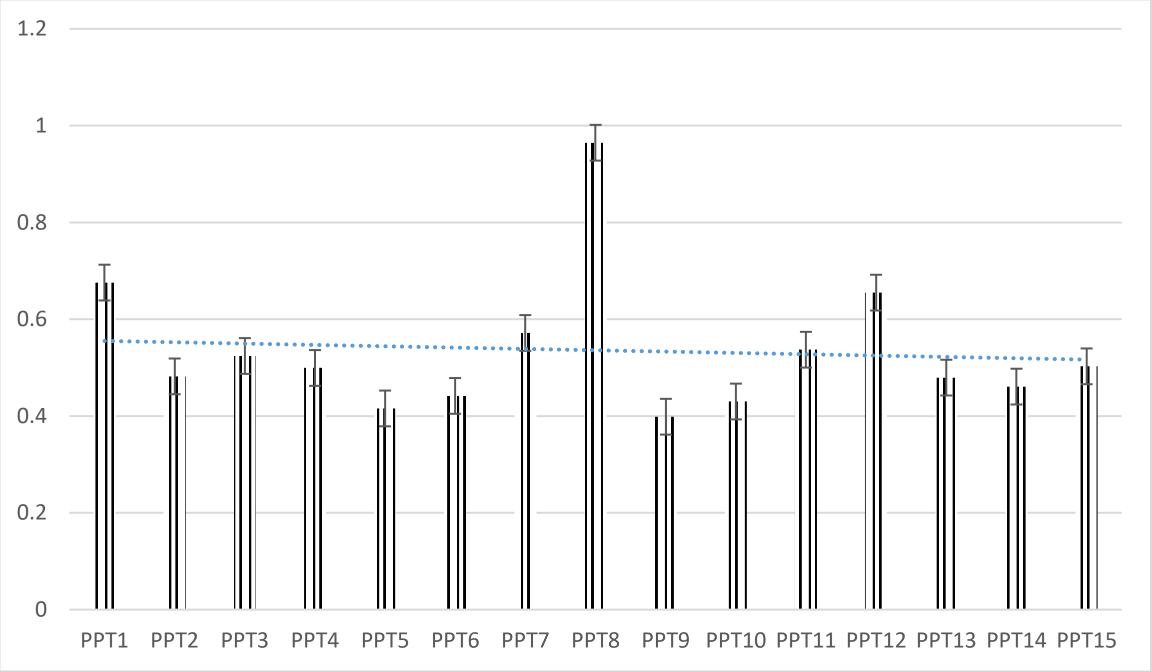

Figure 3: The utility degree values.

3.1 Analysis

We analyze the results of the proposed model to show the strength of the proposed model. We conducted the sensitivity analysis to show the stability of the results. We change the weights of the criteria by eleven cases and then rank the alternatives based on these cases. We put one criterion with 0.13 weights, then all criteria are equal weights as shown in Figure 4.

Then we rank the alternatives by the proposed model under different eleven cases in weight changing. The rank of alternatives is shown in Figure 5. The rank of all alternatives shows that alternative 8 is the best and alternative 9 is the worst. This shows the proposed model is suitable and the results are stable under different cases.

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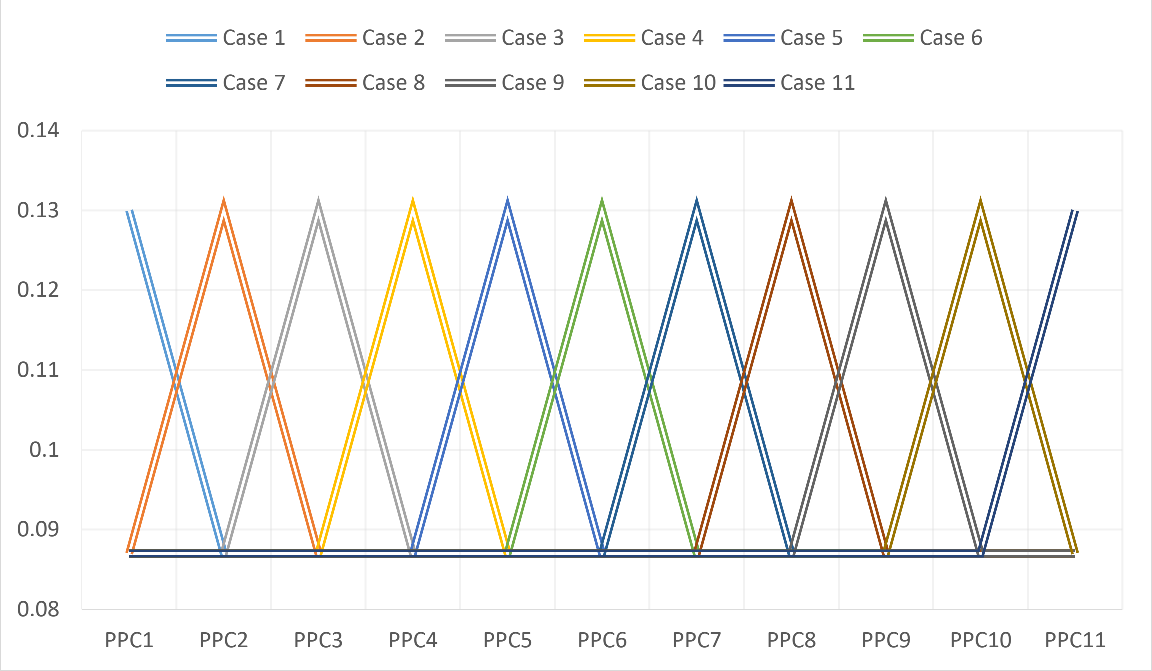

Figure 4: The eleven cases in changing the weights of criteria.

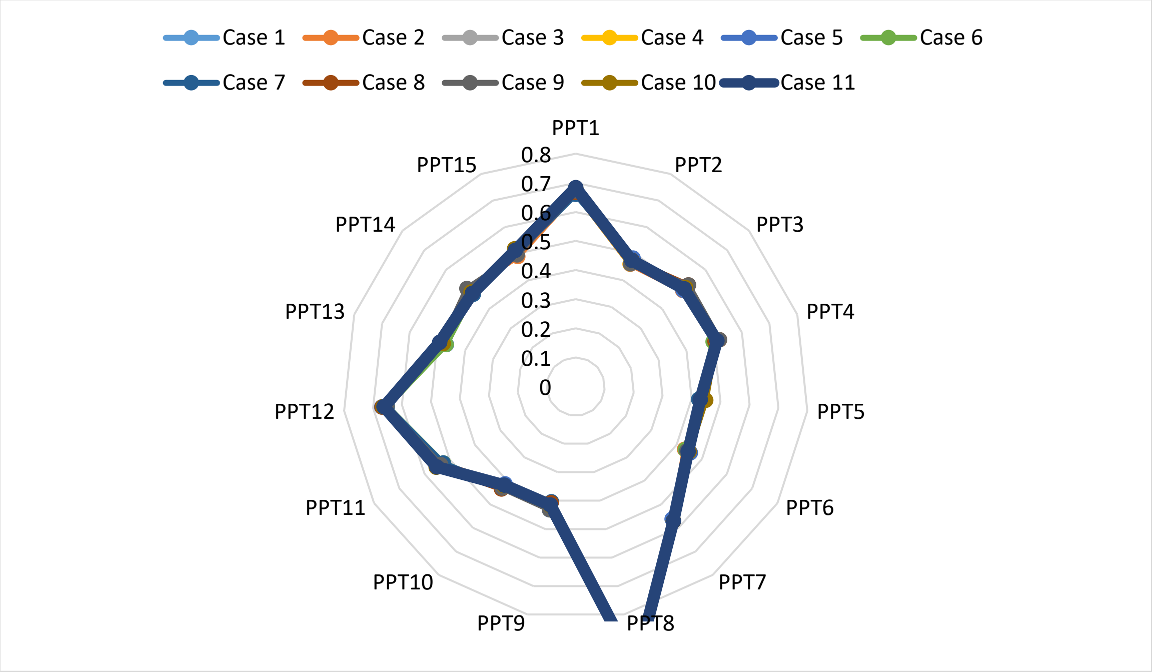

Figure 5: The rank of alternatives under eleven cases.

4. Conclusions

A wind turbine power plant selection requires a thorough analysis of several factors to guarantee its efficacy, efficiency, and adaptability. Developers and operators can increase the likelihood of a wind power plant's successful

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implementation by taking into account issues like wind resource assessment, site selection, turbine technology and design, power generation capacity, grid interconnection, economic viability, environmental impact, permitting and regulatory compliance, operation and maintenance needs, safety and risk assessment, and community engagement.

A well-designed wind power plant starts with accurately evaluating the site's wind resources, guaranteeing steady winds for maximum energy production. Sites are carefully chosen, with attention given to environmental and community consequences and wind availability.

The capacity and efficiency of a wind power plant are closely related to the technology and design of the turbines used in the facility. Selecting the proper turbine types based on site-specific variables, such as wind speed and turbulence, ensures that the facility can efficiently exploit available wind resources.

The electricity produced by the wind plant must be smoothly integrated into the current electrical grid. Hence, it is crucial to take grid connectivity needs into account. Compliance with grid rules, voltage restrictions, and power quality standards provides dependable and steady energy delivery.

Capital investment, operating expenditures, maintenance costs, and income production all factor into whether a wind power facility should be built. A project's long-term profitability and competitiveness may be evaluated by calculating its levelized cost of electricity (LCOE).

Assessing the potential effects on the environment is essential for the long-term success of wind farm projects. Responsible renewable energy production requires minimizing adverse effects on species, habitats, noise levels, aesthetics, and the general environment.

The legal and ethical operation of the wind power plant is guaranteed by the facility's adherence to all applicable environmental, safety, and land use laws and regulations.

By identifying possible dangers and risks connected with wind power plant operations, safety, and risk assessment allows developers and operators to take the necessary steps to protect the safety of personnel and the surrounding environment.

Finally, community support and buy-in are critical for a wind farm's success. Positive connections and widespread support for renewable energy projects may be nurtured via outreach to local communities, response to community issues, information dissemination, and reward distribution.

We used an MCDM method to select the best turbines from different alternatives. We used the ARAS method as an MCDM method to rank the alternatives. The ARAS method uses a single-valued neutrosophic set to deal with uncertain information. We used eleven criteria and fifteen alternatives in this study. The economy is the lowest weight, and wind resource is the highest. The ARAS method outcome is that alternative 8 is the best, and alternative 9 is the worst.

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