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# Single Valued Neutrosophic Set with Multi-Criteria Decision Making Methodology for Wind Turbine Development

**Mohamed Abouhawwash [1,*], Nitin Mittal [2], and Asiye Yilmaz Adkinson [3]**

[1] Department of Computational Mathematics, Science, and Engineering (CMSE), Michigan State University, East Lansing, United States; abouhaww@msu.edu.

[2] Department of Industry 4.0, Skill Faculty of Engineering and Technology, Shri Vishwakarma Skill University, 121102, Palwal, Haryana, India; mittal.nitin84@gmail.com; nitin.mittal@svsu.ac.in.

[3] Department of Animal Science, Erciyes University, Kayseri, Turkey; ayadkinson@erciyes.edu.tr.

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## Abstract

Taller hubs and longer blades make wind turbines more practical and economical than their predecessors because they lower the energy production cost per unit. Nonetheless, these buildings stand out more in the environment because of their larger scale. As wind turbine exposure increases, communities become more concerned about the environment and economy. Thus, a conflict arises between the benefits of increased visibility and reduced wind energy prices as wind turbines become bigger. Most MCDM applications emphasise the significance of wind turbine visibility, which they define as the separation from populated areas, coastal regions, etc. The increased distance from a possible turbine location lessens the influence of visibility, or vice versa. This supposition contributes to the MCDM's visible effects in part. On the other hand, determining visibility may provide more accurate and practical geographic data to be used as a determining factor. This study used an MCDM methodology to show the relationships between wind turbine criteria. The DEMATEL method is an MCDM method used to show wind turbine weights. The DEMATEL method shows the relationships between criteria. There are 12 criteria used in this study. The DEMATEL method was integrated with the single-valued neutrosophic set (SVNS) to overcome uncertainty in the evaluation process.

**Keywords:** Wind Turbine; Multi-Criteria Decision Making; Neutrosophic Set; Decision Making; Uncertainty; Energy.

## 1 | Introduction

With the many strategic, financial, and environmental benefits that come with diversifying energy sources, renewable energy supply has emerged as one of the main concerns for contemporary societies. Renewable energy sources are now grabbing the attention of communities and governments throughout the globe [1].

Despite amazing social acceptability in communities, over fifty years of experience with industrial wind power production have shown significant environmental and social problems emerging from visibility. For reasons related to the economy, health, environment, and landscape quality, visibility concerns are of relevance to the general public. This result is often the result of increasing turbine capacity and numbers [2, 3].

Corresponding Author: abouhaww@msu.edu

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Wind turbine placement is a complex decision-making process. Numerous elements play a role in the decision-making process, which adds to the complexity of this issue. The ultimate aim of decision-making is to find the best possible trade-off between the environmental and social costs of electricity production and its efficiency [4].

Multi-criterion decision-making (MCDM) is a significant area within operation research. It attempts to provide alternative ranks as answers to decision-making difficulties by assessing alternatives' performance or pairwise preference relations concerning specific criteria. The ubiquitous use of computers, the Internet, and digital technologies, simplifying data accumulation, defines the current information era. MCDM models may be supplied with parameters like criterion weights, subjective preferences, and objective performance based on data gathered from surveys or historical records. An MCDM model, for instance, may determine consumer cognition about the performance of goods and services based on data from online reviews [5].

However, the information age also presents difficulties for MCDM, including rapidly increasing data volumes, many data dimensions, poor data correlation, various data types, and dispersed data storage. It is an exciting challenge to investigate how to fully use actual data in the era of information to apply MCDM from theoretical numerical computations to real-world applications.

One multi-criteria decision-making (MCDM) technique in the literature is the decision-making trial and evaluation laboratory (DEMATEL) approach. To address the intricate and interconnected issues, the Science and Human Affairs Programme of the Battelle Memorial Institute of Geneva first created the DEMATEL between 1972 and 1976. One of the structural modelling strategies that may determine the interdependencies of criteria via causality diagrams and bidirectional analysis is this approach, as opposed to other MCDM methods like the analytic hierarchy process (AHP), where assessment requirements are independent. The causal diagram illustrates the fundamental idea of contextual linkages and the degrees of impact among the components or criteria using digraphs instead of directionless graphs [6].

This approach has been used to establish and analyse the cause-and-effect connection between the assessment criteria. Stated differently, the DEMATEL establishes the interdependencies between assessment criteria or elements. To put it another way, the DEMATEL is a thorough process for creating a foundational model that includes causal relationships between many intricate criteria of decision issues. All assessment criteria are divided into two groups using the DEMATEL; the first group is the cause group, and the second is the effect group. Due to these advantageous qualities, DEMATEL has been effectively used in many contemporary decision-making issues. In DEMATEL, pairwise comparisons between criteria are quantified using an accurate numerical scale supplemented by five language phrases [7].

Despite these benefits, DEMATEL's linguistic terminology has several drawbacks. Because more than real-number-based language scales are needed to offer a competent assessment or judgement, most of the information is often expensive and, more significantly, lacks specifics. Furthermore, because of the limited or lack of information, eliciting decision-makers views via these language measures may be interpreted incorrectly [8].

In reality, the decision-making process may become more complicated if the viewpoints of decision-makers are clear or require an appropriate understanding of a subject. Neutronosophic sets were developed to solve the problem of handling incomplete information. To facilitate its application to actual scientific and technical domains, neutrosophic sets were expanded to single-valued neutrosophic sets (SVNSs) a year later. Because SVNSs are so straightforward, additional scientific knowledge—such as aggregation operators, correlation analyses, scoring functions, distance, and similarity measures—has been integrated with these sets [9].

## 2 | Single Valued Neutrosophic DEMATEL Method (SVN-DEMATEL)

This section introduces the steps of the DEMATEL method with the single-valued neutrosophic set. We used the single-valued neutrosophic numbers to evaluate the criteria and alternatives. The DEMATEL method is used to show the criteria weights and the relationships between criteria [10]. This study used the DEMATEL method to show the weights of factors in the wind turbine. Figure 1 shows the steps of the SVN-DEMATEL method.

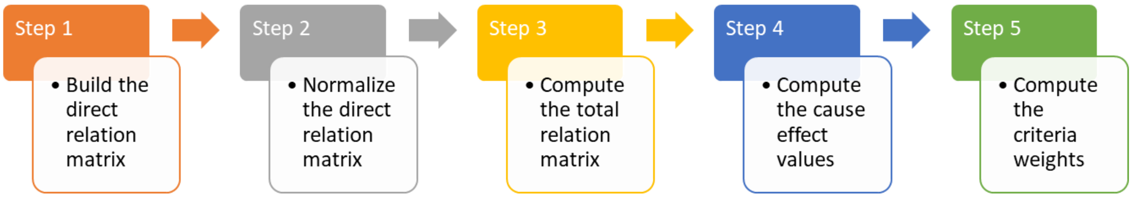


**Figure 1**. The steps of SVN-DEMATEL.

**Step 1.** Build the direct relation matrix.

The pairwise comparison matrix is built between criteria to show the direct relation matrix. The direct relation matrix is built as:

$$D = \begin{bmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{n1} & \cdots & d_{nn} \end{bmatrix}_{n \times n} \quad i, j = 1, 2, \dots, n \tag{1}$$

**Step 2.** Normalize the direct relation matrix.

The direct relation matrix is normalized by using Eqs. (2) and (3).

$$Y = k \times D \tag{2}$$

$$k = \max_{i,j} \left\{ \frac{1}{\max_i \sum_{j=1}^{n} |d_{ij}|}, \frac{1}{\max_j \sum_{j=1}^{n} |d_{ij}|} \right\} \tag{3}$$

**Step 3.** Compute the total relation matrix.

The total relation matrix is built by using Eqs. (4) and (5).

$$T = \begin{Bmatrix} Y + Y^2 + Y^3 + Y^4 + \cdots + Y^l \\ Y(I + Y + Y^2 + Y^3 + Y^4 + \cdots + Y^{l-1})(I - Y)(I - Y)^{-1} \\ Y(I - Y^l)(I - Y)^{-1} \end{Bmatrix} \tag{4}$$

$$T = Y(I - Y)^{-1} \tag{5}$$

**Step 4.** Compute the cause effect values.

The cause effect values are computed by using Eqs. (6) and (7).

$$r = [r_{ij}]_{n \times 1} = \left[ \sum_{j=1}^{n} t_{ij} \right]_{n \times 1} \tag{6}$$

$$c = [c_{ij}]_{n \times 1} = \left[ \sum_{i=1}^{n} t_{ij} \right]_{1 \times n} \tag{7}$$

**Step 5.** Compute the criteria weights.

The criteria weighs are computed by using the normalized weighted method.

# 3 | Results

This section introduces the results of analysis criteria related to wind turbine development—the single-valued neutrosophic set used to overcome the uncertainty in the evaluation process. The experts and decision-makers evaluated the requirements using their opinions, and then we used the single-valued neutrosophic numbers to assess the criteria. The experts used 12 criteria for wind turbines, as shown in Figure 2.


**Figure 2**. The 12 wind turbine criteria.

**Step 1**. Build the direct relation matrix.

The pairwise comparison matrix is built between criteria to show the direct relation matrix. The direct relation matrix is built by using Eq. (1).

**Step 2.** Normalize the direct relation matrix.

The direct relation matrix is normalized by using Eqs. (2) and (3) as shown in Table 1.

**Step 3.** Compute the total relation matrix.

The total relation matrix is built by using Eqs. (4 and 5) as shown in Table 2.

**Step 4.** Compute the cause-and-effect values.

The cause-and-effect values are computed by using Eqs. (6) and (7) as shown in Figure 3.

**Step 5.** Compute the criteria weights.

The criteria weighs are computed using the normalized weighted method, as shown in Figure 4.

**Table 1.** The normalized direct relation matrix.

| | $WTC_1$ | $WTC_2$ | $WTC_3$ | $WTC_4$ | $WTC_5$ | $WTC_6$ | $WTC_7$ | $WTC_8$ | $WTC_9$ | $WTC_{10}$ | $WTC_{11}$ | $WTC_{12}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $WTC_1$ | 0.236 | 0.055696 | 0.124136 | 0.17582 | 0.22774 | 0.124136 | 0.14986 | 0.23246 | 0.124136 | 0.107616 | 0.055696 | 0.149152 |
| $WTC_2$ | 1 | 0.236 | 0.201072 | 0.124136 | 0.149152 | 0.14986 | 0.124136 | 0.087084 | 0.124136 | 0.149152 | 0.23246 | 0.153872 |
| $WTC_3$ | 0.448669 | 0.276995 | 0.236 | 0.149152 | 0.124136 | 0.14986 | 0.124136 | 0.227268 | 0.124136 | 0.124136 | 0.124136 | 0.124136 |
| $WTC_4$ | 0.316779 | 0.448669 | 0.373418 | 0.236 | 0.23128 | 0.14986 | 0.124136 | 0.22774 | 0.124136 | 0.164728 | 0.149152 | 0.08614 |
| $WTC_5$ | 0.24456 | 0.373418 | 0.448669 | 0.240816 | 0.236 | 0.15694 | 0.124136 | 0.16284 | 0.14986 | 0.124136 | 0.23246 | 0.124136 |
| $WTC_6$ | 0.448669 | 0.371654 | 0.371654 | 0.371654 | 0.354887 | 0.236 | 0.060416 | 0.149152 | 0.124136 | 0.149152 | 0.124136 | 0.124136 |
| $WTC_7$ | 0.371654 | 0.448669 | 0.448669 | 0.448669 | 0.448669 | 0.921875 | 0.236 | 0.202016 | 0.124136 | 0.124136 | 0.227032 | 0.149152 |
| $WTC_8$ | 0.239594 | 0.639566 | 0.245067 | 0.24456 | 0.342029 | 0.373418 | 0.275701 | 0.236 | 0.055696 | 0.202016 | 0.202016 | 0.124136 |
| $WTC_9$ | 0.448669 | 0.448669 | 0.448669 | 0.448669 | 0.371654 | 0.448669 | 0.448669 | 1 | 0.236 | 0.124136 | 0.14986 | 0.076936 |
| $WTC_{10}$ | 0.517544 | 0.373418 | 0.448669 | 0.338109 | 0.448669 | 0.373418 | 0.448669 | 0.275701 | 0.448669 | 0.236 | 0.124348 | 0.124136 |
| $WTC_{11}$ | 1 | 0.239594 | 0.448669 | 0.373418 | 0.239594 | 0.448669 | 0.245322 | 0.275701 | 0.371654 | 0.447903 | 0.236 | 0.22774 |
| $WTC_{12}$ | 0.373418 | 0.361963 | 0.448669 | 0.646575 | 0.448669 | 0.448669 | 0.373418 | 0.448669 | 0.723926 | 0.448669 | 0.24456 | 0.236 |

**Table 2.** The total relation matrix.

| | $WTC_1$ | $WTC_3$ | $WTC_4$ | $WTC_5$ | $WTC_6$ | $WTC_7$ | $WTC_8$ | $WTC_9$ | $WTC_{10}$ | $WTC_{11}$ | $WTC_{12}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $WTC_1$ | -0.30088 | -0.14505 | -0.05744 | -0.01292 | -0.10053 | -0.0242 | -0.00583 | -0.04479 | -0.05715 | -0.08695 | 0.004553 |
| $WTC_2$ | 0.286955 | -0.25417 | -0.19803 | -0.1703 | -0.20298 | -0.08489 | -0.1684 | -0.05409 | -0.05912 | -0.02603 | 0.002098 |

| $WTC_{12}$ | $WTC_{11}$ | $WTC_{10}$ | $WTC_{9}$ | $WTC_{8}$ | $WTC_{7}$ | $WTC_{6}$ | $WTC_{5}$ | $WTC_{4}$ | $WTC_{3}$ |
|---|---|---|---|---|---|---|---|---|---|
| -0.99262 | -0.232 | -0.45346 | -0.48058 | -0.2639 | -0.35126 | -0.10026 | -0.2447 | -0.13196 | -0.0569 |
| -0.37473 | -0.26932 | -0.15981 | -0.26959 | -0.24264 | -0.08526 | -0.04684 | 0.016261 | -0.05568 | -0.1463 |
| -0.10647 | -0.20792 | -0.21114 | -0.19624 | -0.19674 | -0.0487 | -0.02395 | -0.14444 | -0.15026 | -0.15152 |
| -0.30827 | -0.32148 | -0.10116 | -0.20891 | -0.10392 | -0.08592 | -0.04068 | -0.17231 | -0.1433 | -0.16838 |
| -0.24096 | -0.15042 | -0.11642 | -0.0918 | -0.0784 | 0.250183 | -0.23626 | -0.23085 | -0.2314 | -0.1456 |
| -0.11976 | -0.13501 | 0.027952 | -0.03912 | -0.07186 | -0.25644 | -0.1989 | -0.12434 | -0.11142 | -0.06973 |
| -0.11892 | -0.1977 | -0.21246 | 0.24899 | -0.28772 | -0.38445 | -0.17652 | -0.15622 | -0.11142 | -0.04233 |
| 0.135121 | -0.02093 | -0.01216 | -0.32382 | -0.20468 | -0.22563 | -0.0934 | -0.06327 | -0.09881 | -0.06491 |
| -0.09931 | 0.025491 | -0.18776 | -0.26003 | -0.05175 | -0.1893 | -0.06979 | -0.07906 | -0.0442 | -0.05859 |
| -0.2142 | -0.19782 | -0.19841 | -0.14369 | -0.02708 | -0.07479 | -0.08355 | 0.02227 | -0.04537 | -0.06238 |
| -0.23293 | -0.1096 | -0.17942 | -0.20964 | -0.0667 | -0.091 | -0.04305 | -0.04666 | -0.07024 | -0.01732 |

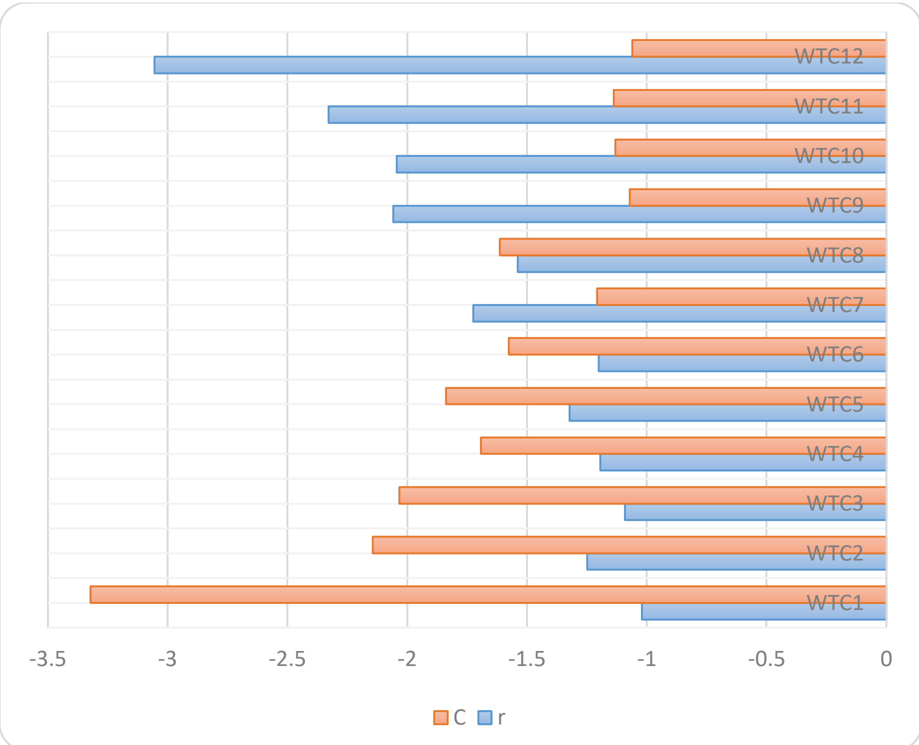


**Figure 3.** The values of $C_{ij} and\ r_{ij}$.

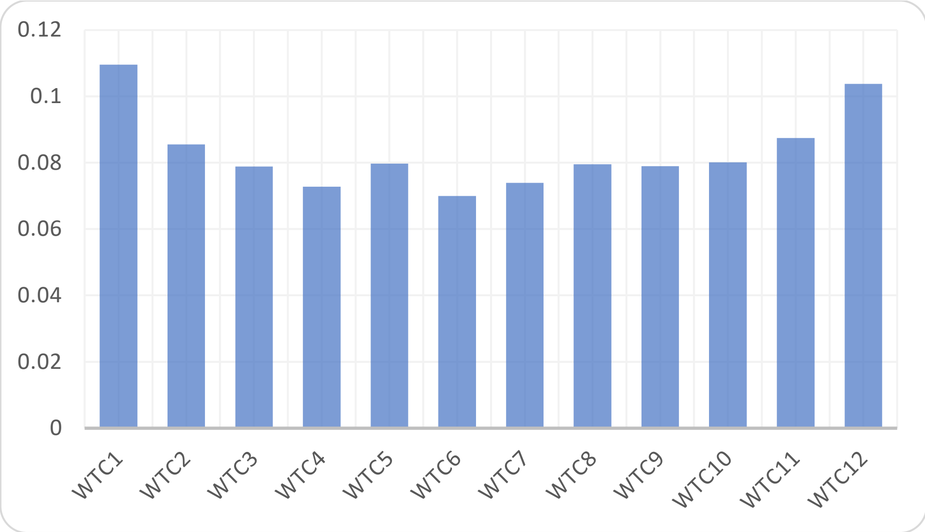


**Figure 4**. The Criteria weights of wind turbine.

## 4 | Conclusions

The worldwide trend towards the growth of wind energy indicates that as the quantity and size of turbines rise, the effects on the ecology and landscape will become more prominent. Consequently, social and environmental considerations must be included in the MCDM for wind turbine locations. The suitability maps and suggested techniques may aid in the strategy development of decision-makers. Investors in the pre-project feasibility stage may also benefit from it. When creating renewable energy projects, land use conflicts may be reduced by including the computed visibility data in the MCDM. Enhancing environmental and landscape quality will prevent local opposition and help boost energy-generating efficiency. This study used a single-valued neutrosophic framework to deal with uncertainty in the evaluation process. The single-valued neutrosophic set is integrated with the DEMATEL method to show the weights and relationships between criteria. There are 12 criteria used in this study.

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## Author Contributaion

All authors contributed equally to this work.

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## Data Availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

## Conflicts of Interest

The authors declare that there is no conflict of interest in the research.

## Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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