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Sustainable Energy Production's Spatial Determination Framework, Based on Multi Criteria Decision Making and Geographic Information System Under Neutrosophic Environment: A Case Study in Egypt

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Abstract: The development of wind energy projects (WEP) have been encouraged, since the last decade. Therefore, WEP grows exponentially, which makes wind energy the trend of energy production for many countries. The success of wind energy project relies on the choice of the appropriate site for wind power plant, often decided by the application of Multi Criteria Decision Making (MCDM). The MCDM methodologies for location selection have a range of shortcomings: (1) the incomplete use of knowledge, (2) the lack of evidence in the decision-making process; and (3) the problem of ignoring the interaction between parameters. This paper presents a new framework for the location selection of wind power stations, based on the incorporating of geographic information system (GIS) and analytical network process (ANP) through neutrosophic environment to cover MCDM's shortcoming. First, an assessment model is built for wind farm site selection. Then, in the specialist committee decision, the bipolar neutrosophic set is used to express missing knowledge. In addition, we take the relationship problem into account by collecting the opinions of experts. Finally, the GIS is used to determine the wind farm potential zones. The suggested framework for the identification of wind farm sites is validated by the use of a case study from Egypt.

Keywords: WEP, neutrosophic, MCDM, GIS

1. Introduction

Electricity consumption is directly growing with time in accordance: urban, technical development, civilians, and agricultural expansion. Energy production is depended mainly on fossil fuels, which: is decreased by time (unsustainable), as well as the high-cost extraction, directly reflected in consumers, and environment pollution effects.

The electricity power importance and its resources, led to the increased interest in alternative and renewable energy resources. Wind is one of the sustainable power resources. Wind power be provided as ample oil fuel, contributes the preservation of the environment, as well as facilitate development in remote area. Wind Energy Location (WEL) is one of the most important factors of wind power production projects, WPL is cornerstone of wind power efficiency and generation cost, as well as to the environmental impacts. Therefore, WEL determination is a vital issue that must be analyzed in depth in order to be effective technically, economically, environmentally, and society. WEL is affected by many factors, these factors must be carefully and systematically identified for making a decision of the holistic approach. Because of the difficulty of trade-off among the alternative available factors and criteria has been the focus of using decision support tools. this paper adopted Multi-Criteria Decision Making (MCDM) approach for WEL determination.

MCDM is one of the operational research sub-disciplines that specifically assesses different competing criteria in decision making1[1]. Although the decision-making preferences must be used to classify the solutions, there is no uniquely appropriate solutions to such problems. Better informed decision-making is assisted by proper structuring and consistent consideration of various parameters for complex problems. MCDM methods demonstrated success in the assessment process in several problem-solving domains.

While the MCDM methods offer an efficient basis for the selection of the ideal location for renewable energy plant with contradictory and multiple criteria, the decision to choose a WEL still has several restrictions. One of challenges is the general uncertainty of determining the selection as the decision takes place before the wind farm is set up, so due to the complexities and location-specific variables, it is often difficult to exactly predict or evaluate correct assessment details. In addition, the reported opinions of experts appear to be uncertain to a large extent, and the level of satisfaction cannot be calculated in an accurate way. Therefore, in an incomplete and imperfect knowledge atmosphere, the site selection decision is made.

The analytic network process (ANP) is one of the best ways to solve dependency and feedback issues between criteria and sub-criteria in decision-making problems under the assumption that they are independent or show self-relation. As there are several complicated interdependencies among the criteria used, there's many ambiguous (non-deterministic) sub-criteria and their connections, the bipolar neutrosophic set-Analytic Network process (BNS -ANP) appears to be an effective tool for determining the best wind farm locations.

There are many factors involved in the wind farm site-selection process, such as social-economic, spatial, ecological and environmental considerations. The Multi-Criteria Decision-Making Approach (MCDM) is efficient in solving dynamic and contradictory multi-layer problems (e.g., benefits, drawbacks, costs, rewards) and is ideal for providing graded decision alternatives to site selection [2]. On the other hand, the Geographic Information System (GIS) instrument, as a powerful method for gathering." preserving, handling, measuring, evaluating, manipulating and mapping geographic information, could play a critical role in the possible evaluation and site selection of wind resources on the basis of its capacity to provide indicator databases and visualized map [3-5].

The integration of MCDM and GIS has also been broadly applicable to site selection analysis. Example studies cover onshore wind farm site selection [3, 6-8]. And Various MCDM techniques are possible to account for the complexity of decision-making under uncertain circumstances and imprecise, especially in the wind farm site selection field. For example, the integration of GIS and the weighted linear combination (WLC) technique was investigated by Gorsevski et al [9] to produce the suitability index of each site under the map layer for Northwest Ohio onshore wind farms.

Sánchez-Lozano et al. [10] First removed unsuitable areas on the basis of relevant legal limitations and consideration of such criteria, and then identified ideal locations for power generation facilities in the Spanish region of Murcia using the ELECTRE-TRI system based on GIS. S. Ali et al. [11] suggested a combined approach to GIS and MCDM to identify the best location for the placement of wind farms. G. Villacreses et al. [2] introduced a GIS with MCDM techniques to determine the optimal site for the construction of wind farms in Ecuador, selecting as the most appropriate location in the Andean zone of Ecuador. Diez-Rodrı́guez et al. [12] developed a methodology for future use in strategic environmental assessment through the application of a technical Group-Spatial Decision Support system (GSDSS) that incorporates information and methods of collective intelligence, complexity theory and geo-prospective.

In order to deal with onshore wind farm site selection, The Analytic Hierarchy Process (AHP) and GIS were combined by S. Ali et al. [3] to classify the ideal sites in Songkhla Province, Thailand for utility-scale onshore wind farms. Gigović et al. [13] developed a model based on the combination of GIS, Decision Making Trial and Assessment Laboratory (DEMATEL), ANP, and Multi-Attributive Boundary Approximation Area Comparison (MABAC), to decide the sites for the construction of wind farms in the province of Vojvodina, Serbia. a fuzzy TOPSIS and Complex Proportional Assessment (COPRAS) model was proposed to select appropriate wind farm locations by Dhiman and Deb [14].

To deal with uncertainty and imprecision Zadeh first proposed the concept of fuzzy sets (FSs) and intuitionistic fuzzy sets (IFs) [15] and [16] respectively. In view of the fact that uncertainties are correlated with the weight determination of the proposed evaluation indicators and their scores relevant to all candidate locations, the fixed values are not adequate to characterize the characteristics of the indicators. As a result, uncertain MCDM approaches have appeared in the field of site selection for wind farms. For example, Ayodele et al. [17] suggested a type-2 fuzzy AHP GIS-based model to decide the appropriate wind farms in Nigeria, where fuzzy sets were used to describe the inconsistency, vagueness and uncertainties of the decision-making process. Y. Wu et al. [18] Firstly, used intuitionist fuzzy numbers and fuzzy measures to represent the intuitive preferences of the experts and to rate the degrees of importance between criteria. Finally, the acceptability of alternate locations for the wind farm project in China was assessed. In addition, in the context of Southeastern Spain [6], the Southeastern Corridor of Pakistan [19] and Vietnam [20], fuzzy AHP and fuzzy TOPSIS have also been shown to be successful in sustainable site selection for onshore wind farms.

Fuzzy focuses only on the membership function (degree of truth) and does not take into account the degree of non-membership (degree of falsehood) and indeterminacy, so fail to represent indeterminacy and uncertainty. Smarandache [21] subsequently developed the neutrosophic set concept, which can deal with indeterminacy. Compared to the fuzzy set and the intuitionistic fuzzy sets, which are unable to deal with indeterminacy effectively. Neutrosophic set (NS) is the generalization of (FSs) and (IFs). numerous types of MCDM approaches are incorporate by neutrosophic set. Neutrosophic sets have many benefits when compared with (FS) and (IFs). Consequently, it is extensively studied by many researchers [22-26].

This paper presents an assessment model for wind farm location selections based on bipolar neutrosophic set (BNS) that can handle vagueness, indeterminacy and improve reliability. BNS is applied with ANP method and GIS to add to the field of wind power station literature. After that, an empirical case study has been considered to illustrate the applicability of this proposed approach.

The remainder of this paper is planned as follows: Section 2 describes the study area. Section 3 describes the bipolar neutrosophic numbers background theory. Section 4 describes Materials and methods. Section 5 presents results and discussion, followed by Section 6 which contains concluding remarks.

2. Study Area

Sinai is a 61,000 km2 triangular peninsula in northeastern Egypt that connects the vast continental land masses of Africa and Asia between latitudes 27° 43' and 31° 19' North and longitudes 32° 19' and 34° 54' East. The peninsula is located between the gulfs of Aqaba and Suez and is bounded to the north by the Mediterranean Sea as shown in Fig. (la). It is split into two administrative regions, with north Sinai covering approximately 27,564 km^2 and south Sinai covering approximately 31,272. Km^2. The Peninsula also covers portions of three governorates; namely Ismailia, Suez, and Port Saied Governorates. Desert plains, sand dunes and sea shores, plateaus and mountainous areas are included in the geographical geography Digital Elevation Model (DEM) of the Sinai Peninsula is shown in Fig. (1b). With a shoreline reaching 205 km, the Mediterranean Sea borders the Peninsula from the north.

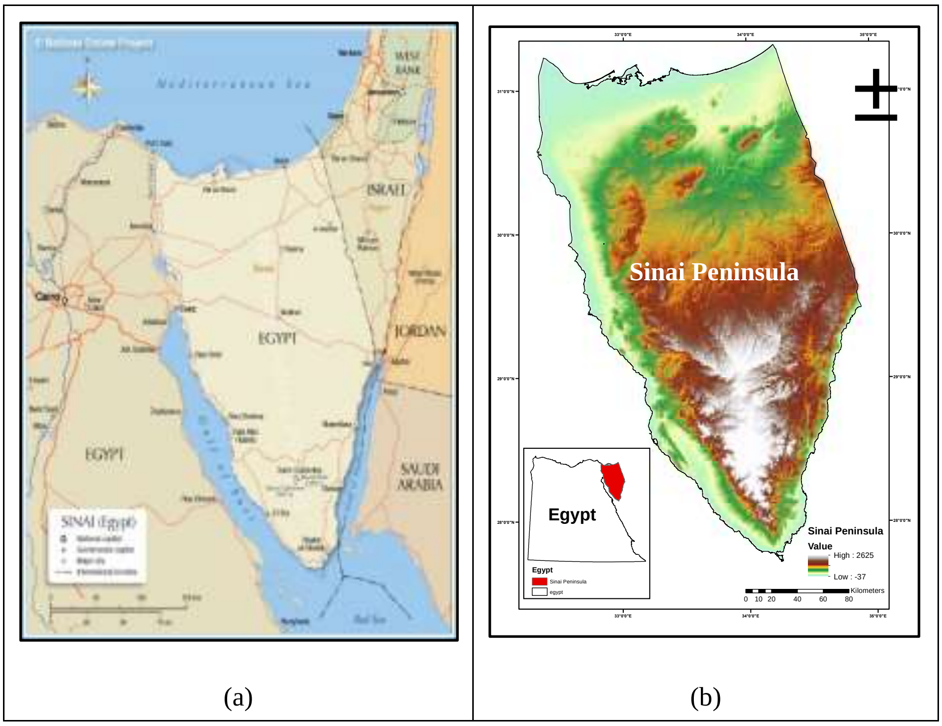


Figure 1. (a) Administrative Boundary, (b) Digital Elevation Model of the Sinai Peninsula.

3. Bipolar Neutrosophic Set (BNS)

Bipolarity is described as the human mind's propensity to reason and make decisions based on positive and negative consequences. Positive statements express what is probable, satisfactory, permissible, expected, or considered suitable. Negative statements, on the other hand, convey what is impossible, forbidden, or rejected [27]. In this section, some important definitions of bipolar neutrosophic numbers (BNNs) are introduced [28].

Definition 3.1 A BNS A in X is defined as an object of the form $A = \{\langle x, T^{+}(x), I^{+}(x), F^{+}(x), T^{-}(x), I^{-}(x), F^{-}(x)\rangle : x \in X\}$ where $T^{+}, I^{+}, F^{+} : X \to [1,0]$ and $T^{-}, I^{-}, F^{-} : X \to [-1,0]$. The positive membership degree $T^{+}(x), I^{+}(x), F^{+}(x)$ represent the truth membership, the indeterminacy membership, and the falsity membership of $x \in A$, respectively. And the negative membership degree $T^{-}(x), I^{-}(x), F^{-}(x)$ represent the truth membership, the indeterminacy membership, and the falsity membership of $x \in A$.

Definition 3.2 Suppose that $\tilde{a}_1 = \langle T_1^{+}, I_1^{+}, F_1^{+}, T_1^{-}, I_1^{-}, F_1^{-}\rangle$ and $\tilde{a}_2 = \langle T_2^{+}, I_2^{+}, F_2^{+}, T_2^{-}, I_2^{-}, F_2^{-}\rangle$ be tow Bipolar Neutrosophic Numbers. Then, there are the following operational rules:

$$\lambda \tilde{a}_1 = \langle 1-(1-T_1^{+})^{\lambda}, (I_1^{+})^{\lambda}, (F_1^{+})^{\lambda}, -(-T_1^{-})^{\lambda}, -(-I_1^{-})^{\lambda}, -\left(1-\left(1-(-F_1^{-})\right)^{\lambda}\right)\rangle \quad (1)$$

$$\tilde{a}_1{}^{\lambda} = \langle (T_1^{+})^{\lambda}, 1-(1-I_1^{+})^{\lambda}, 1-(1-F_1^{+})^{\lambda}, -\left(1-\left(1-(-T_1^{-})\right)^{\lambda}\right), -(-I_1^{-})^{\lambda}, -(-F_1^{-})^{\lambda}\rangle \quad (2)$$

$$\tilde{a}_1 + \tilde{a}_2 = \langle T_1^{+} + T_2^{+} - T_1^{+}T_2^{+}, I_1^{+}I_2^{+}, F_1^{+}F_2^{+}, -T_1^{-}T_2^{-}, -(-I_1^{-} - I_2^{-} - I_1^{-}I_2^{-}), -(-F_1^{-} - F_2^{-} - F_1^{-}F_2^{-})\rangle \quad (3)$$

$$\tilde{a}_1 . \tilde{a}_2 = \langle T_1^{+} + T_2^{+}, I_1^{+} + I_2^{+} - I_1^{+}I_2^{+}, F_1^{+} + F_2^{+} - F_1^{+}F_2^{+}, -(-T_1^{-} - T_2^{-} - T_1^{-}T_2^{-}), -I_1^{-}I_2^{-}, -F_1^{-}F_2^{-}\rangle \; Where\ \lambda > 0 \quad (4)$$

Definition 3.3 Suppose that $\tilde{a}_1 = \langle T_1^{+}, I_1^{+}, F_1^{+}, T_1^{-}, I_1^{-}, F_1^{-}\rangle$ be a Bipolar Neutrosophic Number. Then, the score function $S(\tilde{a}_1)$, accuracy function $A(\tilde{a}_1)$ and certainty function $C(\tilde{a}_1)$ of a Bipolar Neutrosophic Number can be defined as follows:

$$S(\tilde{a}_1) = (T_1^{+} + 1 - I_1^{+} + 1 - F_1^{+} + 1 + T_1^{-} - I_1^{-} - F_1^{-})/6 \quad (5)$$

$$A(\tilde{a}_1) = T_1^{+} - F_1^{+} + T_1^{-} - T_1^{-} \quad (6)$$

$$C(\tilde{a}_1) = T_1^{+} - F_1^{-} \quad (7)$$

4. Materials and Methods

This section describes the proposed framework and the used data sets with its resources. The framework is an integration among BNS, ANP, and GIS (BAG).

4.1 Data Set

Table (1) summarizes the researcher's data set that were collected from numerous resources including governmental agencies, open sources, and related literature. GIS and remote sensing technology have been used in combination to process, Integrate, and analyze spatial data. The software used for this study are ArcGIS 10.3 and Global Mapper v17.1 to make them usable in the wind farm site selection model. The weights of the criteria were generated using the Bipolar neutrosophic set (BNS) and Analytic Network Process (ANP), the mathematical model implemented in Microsoft Excel.

Table 1. Data Sources Used in the Study.

Format	Data Set	Source
Raster	Digital Elevation Model.	United States Geological Survey Earth Explorer.
	Wind Speeds and Directions.	National Authority for Remote Sensing and Space Sciences, Egyptian Metrological Authority, The Global Wind Atlas, NASA Power Data Access Viewer.
	Land Cover.	Food and Agriculture Organization AFRICOVER Data
	Birds Flyway.	Bird Life International
Vector	Roads, Urban Areas, Water Surfaces, Airports, Power Lines.	Egyptian Survey Authority
	Protected Areas.	Egyptian Environmental Affairs Agency

4.2 BAG Framework Description

BAG utilizes GIS capabilities in geospatial data management and MCDM versatility to merge accurate data (e.g., slope, land usage, elevation, etc.) with value-based data (e.g., specialists views, standards, surveys, etc.) in a neutrosophic framework for the selection of suitable locations for wind farms. the BAG framework is comprising the following stages as shown in Fig.(2) .

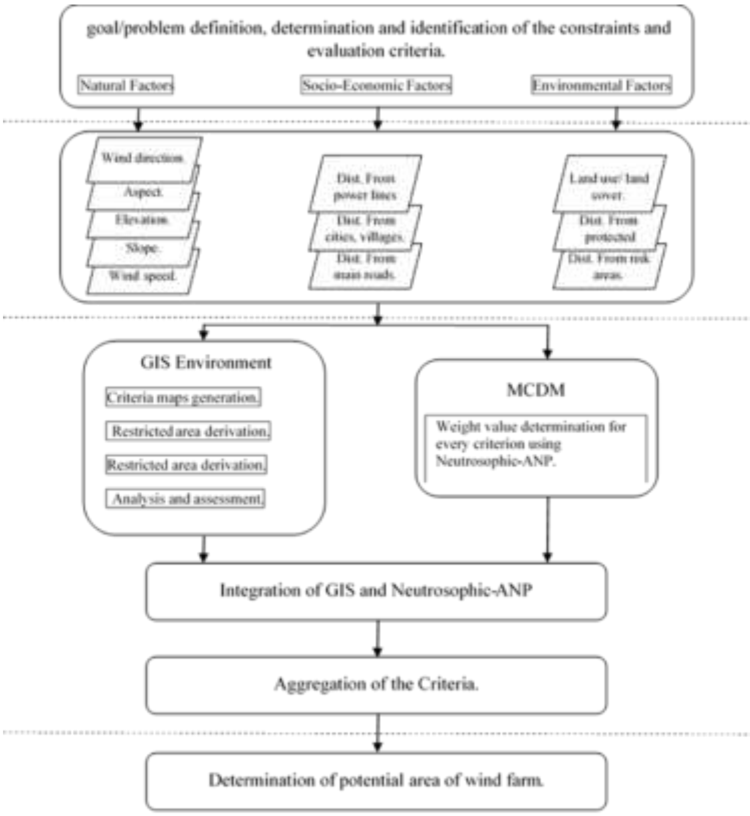


Figure 2. BAG Framework.

Stage 1: preliminary study, Data acquisition and Pre-Processing

This stage involves definition of goal/problem, determination and identification of the constraints and evaluation criteria, and analysis of generally suitable sites.

Stage 2: Restricted area identification

Due to residential areas, water bodies, natural reserves or protected areas, it is deemed impractical to install such a system in such an environment. The definition of that area helps the definition of the area of usable zones for the construction of a wind farm system to be eliminated. First, certain areas are excluded which, due to factual factors and legal requirements, may be deemed to be unsuitable for locating wind farms. Buffer zones, i.e., minimal lengths, across these regions are also excluded in some cases under Egyptian legislation.

The procedure of exclusion is applied in ArcGIS. The BUFFER tool is used to build a buffer zone around a specified type of field. In a next step all feature datasets are transformed into a raster dataset. then, Based on Boolean logic, the criteria are assigned a true or false value by the IS NULL and CON tools. All restricted areas are marked as false and therefore obtain a value score of 0. After that, "multiply' all restrictions. Finally, the exclusion area map will show the technically available maximum land for wind energy development in the study area.

Stage 3: Criteria Standardization

Although each criteria attribute has its measuring scale, standardization is used to perform transformation of attributes into a common suitability. that produces transformed attributes in a common reference rate scale. For example, the criteria attributes for each sub-model were transformed from the original values to a common suitability scale ranged from 1-10 (10 means more favorable, and zero means unsuitable pixels).

Stage 4: Analysis, and assessment

After exclusionary areas were identified and excluded from the all area of Study area, the potential suitable area for wind farm construction is the remainder area. This potentially suitable area must be evaluated to select the preferred sites. In this study, we used ArcGIS spatial analyst which provides affluence set of spatial analysis and modeling tools and functions for both raster and vector data. The analytical capabilities of Spatial Analyst facilitate spatial manipulation and generate data based on spatial analysis and displaying the results of spatial analysis. Here are described the GIS analytical procedures that have been applied individually or used in sequence within ArcGIS to evaluate the initial suitability for wind farm construction:

1. Euclidian distance analysis: Euclidian distance tool describes each cells relationship to a source based on the straight-line distance. The output of this tool is raster map .
2. Reclassify analysis: Provide a variety of methods that allow you to reclassify or change input cells to alternative values.

Stage 5: Bipolar Neutrosophic ANP application

In main nine steps, Bipolar Neutrosophic ANP can be summed up as follows :

Step 1. Model Builder: Building a model and transforming an issue into a network structure concept. There must be an accessible transformation of a problem into a logical structure, such as a network. The problem is transformed into a network system at this step, where all aspects can contact with each other.

Step 2. Experts Determination: A process to select a committee of experts including scholars and professionals in relevant fields such as social sciences, energy, environmental protection and economy. It is important to take into account the diverse perspectives of experts based on their background and areas of expertise.

Step 3. Linguistic Evaluation: Experts suggest their linguistic expressions for assessing the relative importance of criteria.

Step 4. BNS Transformation: Transforms the linguistic expressions to Bipolar neutrosophic numbers. For criteria weights, the linguistic expressions are as shown in Table (2).

Table 2. Bipolar Neutrosophic Scale for Comparison Matrix [28].

Linguistic Expressions	**Bipolar Neutrosophic Numbers Scale** $\langle T^+(x), I^+(x), F^+(x), T^-(x), I^-(x), F^-(x)\rangle$
Absolutely Influential (AI)	$\langle(0.9,0.1,0.1), (-0.4,-0.8,-0.9)\rangle$
Very Highly Influential (VHI)	$\langle(0.8,0.5,0.5), (-0.3,-0.8,-0.8)\rangle$
Equally Influential (EI)	$\langle(0.5,0.5,0.5), (-0.5,-0.5,-0.5)\rangle$
Influential (I)	$\langle(0.4,0.2,0.7), (-0.5,-0.2,-0.1)\rangle$
Almost Influential (ALI)	$\langle(0.1,0.8,0.7), (-0.9,-0.2,-0.1)\rangle$

Step 5. Deneutrosophication: Determine the score value of linguistic terms for each factor, Using the Eq. (5) for converting bipolar neutrosophic numbers into crisp values.

Step 6. Pair-wise Comparisons Constructions: Constructing a pair-wise relation of all the decision-making variables and estimate the criteria priority . Decision elements for each group are compared pairwise, equivalent to the pair-wise comparison conducted in AHP. Groups themselves are also evaluated on the basis of their position and influence on the achievement of the goals and on the interdependencies between each group's criteria. Through the eigenvector, the impact of criteria on each other can be presented .

Step 7. Generate a Super Matrix: In order to achieve overall objectives in an interconnected environment, Vectors of internal importance must be inserted into unique columns of the matrix which is called the super matrix. It is essentially a partition matrix that displays the relations among two groups in a system. The hierarchy's super matrix can be defined as:

$$W_h = \begin{bmatrix} 0 & 0 & 0 \\ W_{21} & 0 & 0 \\ 0 & W_{32} & I \end{bmatrix} \quad (8)$$

Where in this super matrix, $W_{21}$is a vector that demonstrates the impacts of the target on criteria, W_{32} demonstrates the impacts of criteria on alternatives, and I represents the unit matrix. If the parameters for inner relations are used, the hierarchy model will be transformed to network model. Criteria interactions are by inserting W_{22} into the W_h super matrix to be the W_n matrix.

$$W_n = \begin{bmatrix} 0 & 0 & 0 \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & I \end{bmatrix} \quad (9)$$

Step 8. Constructing the weighted super matrix: This matrix is known as the initial super matrix. For obtaining the unweighted super matrix the inner priorities vectors, matrices and elements replaced in the initial super matrix. By multiplying the unweighted super matrix values in the group matrix, the weighted super matrix is obtained. Then, Using Eq. (10) in the final stage for calculating the limited super matrix.

$$\lim_{k \to \infty} W^k \quad (10)$$

Step 9. Choosing the right choice: In the limited super matrix, the alternatives final weight obtaining from the alternative's column. An alternative is regarded to be the right choice when becoming the greatest weight in this matrix. In the proposed technique, Bipolar neutrosophic ANP can be applied for determining the weights of the criteria. After that, the weights of the criteria can be used in ARCGIS to determine alternatives.

Stage 5: Aggregation of the Criteria:

It is important to aggregate the criteria after calculating of the clusters/criteria weights. WLC is used in the requirements aggregation process. Each standardized criteria map (each cell within each map) is multiplied by the weight of its criteria and the results are then summed. To integrate the assessment (factors) criteria as per the WLC process, the following mathematical expression was used:

$$S = \sum W_i X_i \quad (11)$$

Where S is suitability, W_i is the normalized value of the weight of factor i, and X_i is the criterion score of factor i.

In the next stage, the required locations need to be segregated by removing the cells from the suitability map with the highest values for showing the position of wind farms. By integrating the arithmetic operations and queries in the GIS application, the cells are filtered then identifying wind farm installation sites.

5. Results and Discussions

In accordance with recent developments and political developments in Egypt over the past few years, and in line with the trend of the State in promoting the use of renewable energies in most industrial, agricultural, tourism and other applications, nevertheless the issue of selecting wind farm site still prominent. Decision making process on choosing the best site is a big issue for MCDM. In this research, the solution to the problem has been achieved in an environment of ambiguity (fuzziness) and uncertainty by merging the Bipolar Neutrosophic, ANP, and GIS in the following steps :

Step 1: preliminary study, Data acquisition and Pre-Processing

In this research, we used a data-set that included climatic, topographic, hydrologic, and geological factor. Based on several literatures, case studies concerning wind farm site selection and local conditions, different criteria were reviewed and eleven criteria were selected to evaluate the suitable sites for wind farms, criteria have been classified into three main groups because groups play an important role in the ANP method; natural, environmental and socio-economic factors. These were the most important criteria for selecting suitable sites.

1. Natural factors

Includes wind speed, Elevation, Slope, Aspect direction, and wind direction. Wind speed is a critical factor to generate wind turbine's electricity. To order to produce wind energy, wind speed above certain rates is vital [7]. The height has an impact on the technical capability of installing a wind-turbine and maximizes construction and maintenance costs, the high-altitude sites (above 1500 m.a.sl) or near cliffs are usually not appropriate for installing wind turbines [29-31]. Sloping grounds are considered to be less suitable for wind turbine improvement, which increases the cost of building and maintaining turbines dramatically [7, 32]. Terrain location should be taken into account, as the ideal factor. Aspect relative to the direction of the wind [33], and wind turbines are located through the prevailing wind direction to be effective.

2. Environmental factors

Include Proximity to airports, distance to environmental interest areas; and land cover/land use of ground surface. The distance between airports and wind turbines affects the safety of flights, therefore, the location of the for airports factor should be taken into account. Moreover, Wind turbines may interfere with radio transmissions, radar and microwave signals due to their heights hence the need to site them away from airports [34]. when deciding where turbines should be installed, the wind turbine effect on environmental interest areas (protected areas, bird migration flyway) should be taken into account [35,36]. Moreover, the possibility of floods happening near wind farms during the winter should be taking into account as a crucial factor affects the functionality of the turbines, and in order to prevent damage to the turbine components, wind turbine fins are lowered and disconnected. And all the mechanical parts of wind power turbines have to be kept away from the water. One of the most important factors for energy investments is land use/land cover. Wind farms should be installed in the area in which they negligibly interfere with existing land use outside protected areas, artificial surfaces, wetlands, aquatic and forest areas [33].

3. Socio-economic factors

Include Proximity to power grid, Proximity to cities, distance to roads. In order to reduce the costs associated with the construction of wind farms and to reduce electric transport costs generated in the national energy distribution system, wind farms should be located in the vicinity of the current transmission grids [33]. One of the key technical considerations, therefore, is the need to shorten the distance between wind-turbines -as the source of renewable energy- and the existing national energy network. The wind farm must be located far from the cities and villages to achieve the protection and lower noise interference [33]. Distance to roads has an impact on the expenses of installing and maintaining wind turbines, but due to safety reasons, the location of wind turbines should be properly positioned at a set distance from roads and railways [33].

After that, all maps taken as GIS layers for the whole area of Sinai Peninsula and projected into WGS_1984_UTM_Zone_36N of the Universal Transverse Mercator System (UTM) of projected coordinates. Then all vector data sets were converted to raster data set. Clip or mask the data set with study area boundary, and ensuring that all cell size equal 30×30.

Step 2: Identification and Exclusion of restricted areas.

Table (3) shows the exclusionary criteria and buffer zones for potential wind farms. Based on a predefined criterion, the restrictive method uses the Boolean logic approach to define the possibility of locating a wind farm. Logical math tools represent the right conditions as 1 for the area with a probability of being a wind farm location and false conditions as 0 for an area with an impediment for wind farm locating.

Table 3. The List of Exclusionary Criteria and Corresponding Buffer Distance.

Criteria	Exclusionary Criteria	Buffer Zones
Natural	Elevation	>2000 m
	Slope	>15%

	Wind Speed	<5
Scio-Economic	Roads	0-500 m
	Power Lines	0-500 m
	Urban Areas	0-2500 m
Environmental	Land Cover / Land Use	Water Bodies, Urban Areas.
	Protected Areas	0-2000 m

Step 3: Criteria standardization to a common scale.

For our research, we used the simplest formula for linear standardization which is called the maximum score procedure. The formula divides each raw criterion value by the maximum criterion value as shown in Eq. (12).

$$x'_{ij} = \frac{x_{ij}}{x_j^{max}} \quad (12)$$

Where x'_{ij} is the standardized score for the i^{th} decision alternative and the j^{th} criterion, x_{ij} is the raw data value, and x_j^{max} is the maximum score for the j^{th} criterion.

Step 4: Analysis, and assessment.

Euclidian distance function (multiple buffers) in ArcGIS Spatial Analyst was used to calculate the distance from transmission power lines; urban areas; roads; and protected areas. Then, reclassify analysis function in ArcGIS Spatial Analyst was used to reclassify the study area into classes. The complete classification has been presented in Table (4). Fig. (3) shows an example for the reclassified maps.

Table 4. Criteria Suitability Classes.

Suitability Rating	Classes	Slope	Elevation	Wind Speed	D.F. Roads
3	Most Suitable	0 - 2.5	0 - 50	10.8 - 16.2	0 - 2627
2	Suitable	2.5 - 5	50 - 100	7.6 - 10.8	2627 - 7342
1	Less Suitable	5 - 15	100 - 600	4.4 - 7.6	7342 - 30981
0	Not Suitable	> 15	> 600	2.4 - 4.4	30981 - 58219
Suitability Rating	**Classes**	**D.F. Power Lines**	**D.F. Urban Areas**	**Land Cover / Land Use**	**Protected Areas**
3	Most Suitable	0 - 6557	0 - 4922	Bare Land	> 2000 m
2	Suitable	6557 - 15953	4922 - 12639	-	-
1	Less Suitable	15953 - 48713	12639 - 43710	-	-
0	Not Suitable	48713 - 76364	43710 - 73454	Sabkha	-

Step 5: Constructing the structure of the problem .

The general criteria and sub-criteria for selections are mentioned in Table (5). Fig. (2) presented a schematic diagram of the problem.

Step 6: Determine a committee of decision makers.

Step 7: Use linguistic variables to express the opinion of specialists Using the scales mentioned previously in Table (2).

Step 8: Determine the inner-relationship among the sub-criteria, as in Table (6).

Table 5. Criteria for Wind Farm Selection.

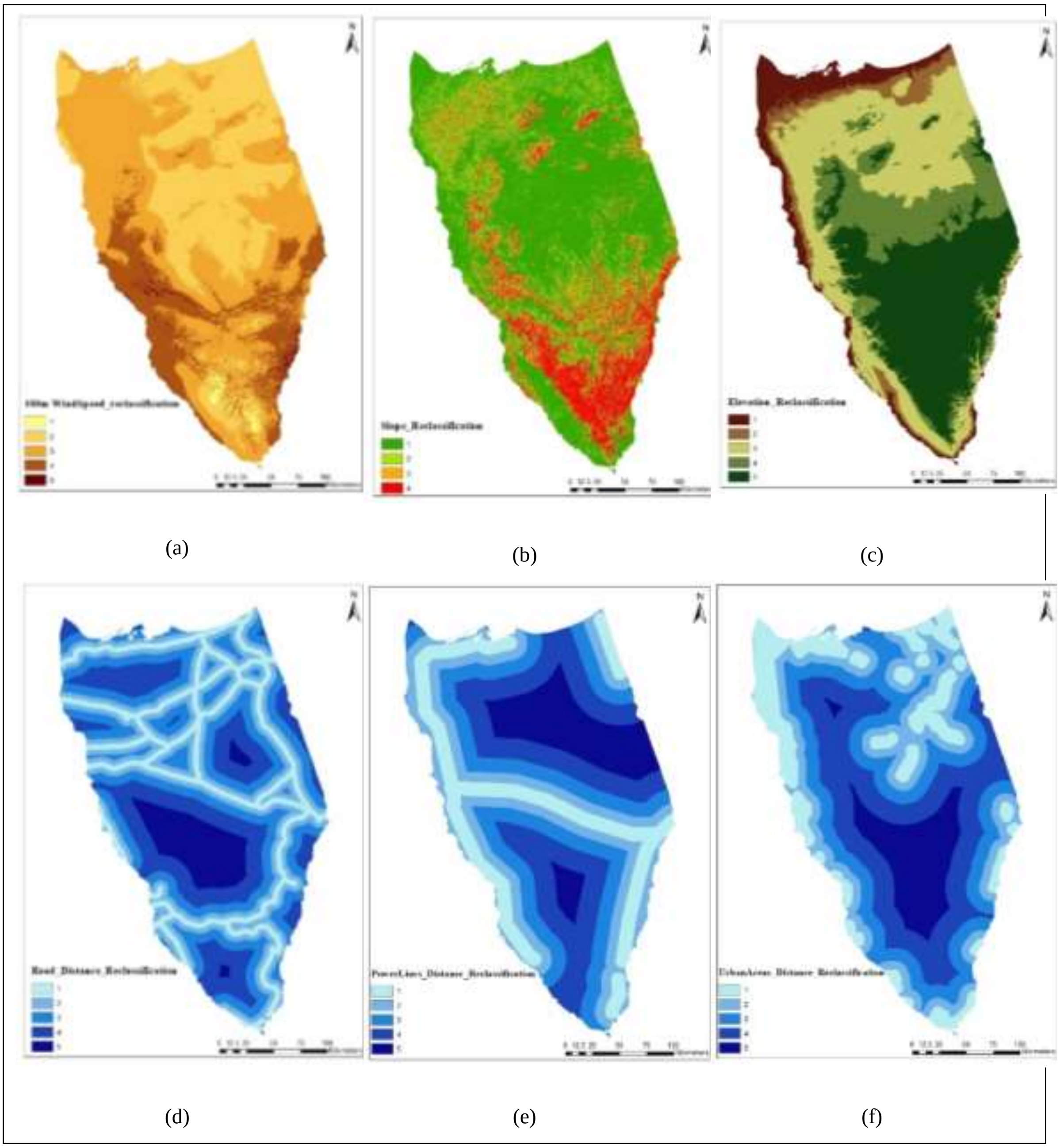
Criteria	Sub-Criteria
Natural (c_1)	Slope (c_{11})
	Wind Direction (c_{12})
	Wind Speed (c_{13})
	Elevation (c_{14})
	Aspect (c_{15})
Scio-Economic (c_2)	D.F. Roads (c_{21})
	D.F. Power Lines (c_{22})
	D.F. Urban Areas (c_{23})
Environmental (c_3)	Land Cover / Land Use (c_{31})
	Protected Areas (c_{32})

Table 6. Sub-criteria Dependencies.

Sub-Criteria	Rely on	Sub-Criteria	Rely on
c_{11}	(c_{12}, c_{22}, c_{31})	c_{21}	$(c_{22}, c_{23}, c_{31}, c_{32})$
c_{12}	(c_{11}, c_{21}, c_{32})	c_{22}	(c_{11}, c_{13}, c_{15})
c_{13}	$(c_{12}, c_{21}, c_{22}, c_{23})$	c_{23}	$(c_{11}, c_{13}, c_{15}, c_{21})$
c_{14}	(c_{13}, c_{21}, c_{32})	c_{31}	(c_{21}, c_{23}, c_{32})
c_{15}	(c_{11}, c_{13}, c_{22})	c_{32}	(c_{14}, c_{21}, c_{31})

Step 9: constructing the pairwise comparison matrix between the main criteria as follows :

- Construct W_{21} as presented in Table (7).
- Replace the linguistic scale by Bipolar Neutrosophic numbers by using Table (2).
- De-neutrosophication of the Bipolar neutrosophic numbers to crisp values as presented in table (8) using Eq. (5).
- Check the consistency by computing the CR of the comparison matrices with less or equal 0.1.
- Calculated the interdependences for sub-criteria as Demonstrated in Tables (9-18).
- Constructed the W_{22} matrix as presented in Table (19).
- Constructed the weight matrix and calculate the weight of criteria using $W_{criteria} = W_{21} \times W_{22}$, as shown in Table (19).



(a) (b) (c)

(d) (e) (f)

Figure 3. Reclassified Factors Maps for: (a) Wind Speeds; (b) Slope; (c) Elevation; (d) Roads; (e) Power Lines; (f) Urban Areas.

Table 7. Pairwise Comparison for W_{21}.

W_{21}	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}	c_{21}	c_{22}	c_{23}	c_{31}	c_{32}
c_{11}	EI	1/I	ALI	1/AI	AI	AI	1/ALI	VHI	1/EI	EI
c_{12}	I	EI	1/VHI	1/ALI	1/VHI	ALI	1/AI	ALI	VHI	1/VHI
c_{13}	1/ALI	VHI	EI	AI	1/AI	AI	EI	AI	EI	ALI
c_{14}	AI	ALI	1/AI	EI	ALI	ALI	AI	1/ALI	1/ALI	ALI

c_{15}	1/AI	VHI	AI	1/ALI	EI	VHI	AI	1/I	1/AI	1/AI
c_{21}	1/AI	1/ALI	1/AI	1/ALI	1/VHI	EI	1/AI	EI	AI	VHI
c_{22}	ALI	AI	1/EI	1/AI	1/AI	AI	EI	AI	1/EI	ALI
c_{23}	1/VHI	1/ALI	1/AI	ALI	I	1/EI	1/AI	EI	AI	1/AI
c_{31}	EI	1/VHI	1/EI	ALI	AI	1/AI	EI	1/AI	EI	ALI
c_{32}	1/EI	VHI	1/ALI	1/ALI	AI	1/VHI	1/ALI	AI	1/ALI	EI

Table 8. W_{21} De-neutrosophication Matrix.

W_{21}	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}	c_{21}	c_{22}	c_{23}	c_{31}	c_{32}	W_{21}**Weight**
c_{11}	0.5	2.609	0.167	1.2	0.833	0.833	6	0.683	2	0.5	0.096
c_{12}	0.383	0.5	1.463	6	1.463	0.167	1.2	0.167	0.683	1.463	0.088
c_{13}	6	0.683	0.5	0.833	1.2	0.833	0.5	0.833	0.5	0.167	0.088
c_{14}	0.833	0.167	1.2	0.5	0.167	0.167	0.833	6	6	0.167	0.098
c_{15}	1.2	0.683	0.833	6	0.5	0.683	0.833	2.609	1.2	1.2	0.100
c_{21}	1.2	6	1.2	6	1.463	0.5	1.2	0.5	0.833	0.683	0.115
c_{22}	0.167	0.833	2	1.2	1.2	0.833	0.5	0.833	2	0.167	0.066
c_{23}	1.463	6	1.2	0.167	0.383	2	1.2	0.5	0.833	1.2	0.109
c_{31}	0.5	1.463	2	0.167	0.833	1.2	0.5	1.2	0.5	0.167	0.063
c_{32}	2	0.683	6	6	0.833	1.463	6	0.833	6	0.5	0.176

Table 9. Interdependencies Matrix of Factor C_{11}.

C_{11}	C_{12}	C_{22}	C_{31}	W_{22}
C_{12}	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.1,0.8,0.7,-0.9,-0.2,-0.1\rangle$	$1/\langle 0.9,0.1,0.1,-0.4,-0.8,-0.9\rangle$	0.217
C_{22}	$1/\langle 0.1,0.8,0.7,-0.9,-0.2,-0.1\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	0.447
C_{31}	$\langle 0.9,0.1,0.1,-0.4,-0.8,-0.9\rangle$	$1/\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	0.337

Table 10. Interdependencies Matrix of Factor C_{12}.

C_{12}	C_{11}	C_{21}	C_{32}	W_{22}
C_{11}	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.9,0.1,0.1,-0.4,-0.8,-0.9\rangle$	$1/\langle 0.1,0.8,0.7,-0.9,-0.2,-0.1\rangle$	0.458
C_{21}	$1/\langle 0.9,0.1,0.1,-0.4,-0.8,-0.9\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	0.288
C_{32}	$\langle 0.1,0.8,0.7,-0.9,-0.2,-0.1\rangle$	$1/\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	0.254

Table 11. Interdependencies Matrix of Factor C_{13}.

C_{13}	C_{12}	C_{21}	C_{22}	C_{23}	W_{22}
C_{12}	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	$1/\langle 0.9,0.1,0.1,-0.4,-0.8,-0.9\rangle$	0.162
C_{21}	$1/\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 1/0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	$\langle 0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	0.312
C_{22}	$1/\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	$\langle 0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$1/\langle 0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	0.269
C_{23}	$\langle 0.9,0.1,0.1,-0.4,-0.8,-0.9\rangle$	$1/\langle 0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	$\langle 0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	0.256

Table 12. Interdependencies Matrix of Factor C_{14}.

C_{14}	C_{13}	C_{21}	C_{32}	W_{22}
C_{13}	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$1/\langle 0.1,0.8,0.7,-0.9,-0.2,-0.1\rangle$	$\langle 0.9,0.1,0.1,-0.4,-0.8,-0.9\rangle$	0.467
C_{21}	$\langle 0.1,0.8,0.7,-0.9,-0.2,-0.1\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$1/\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	0.227
C_{32}	$1/\langle 0.9,0.1,0.1,-0.4,-0.8,-0.9\rangle$	$\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	0.306

Table 13. Interdependencies Matrix of Factor C_{15}.

C_{15}	C_{11}	C_{13}	C_{22}	W_{22}
C_{11}	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$1/\langle 0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	$\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	0.386
C_{13}	$\langle 0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$1/\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	0.283
C_{22}	$1/\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	$\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	0.331

Table 14. Interdependencies Matrix of Factor C_{21}.

C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	W_{22}
C_{22}	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	$1/\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	0.182
C_{23}	$1/\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$1/\langle 0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	$\langle 0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	0.313
C_{31}	$1/\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	$\langle 0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$1/\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	0.247
C_{32}	$\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	$1/\langle 0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	0.258

Table 15. Interdependencies Matrix of Factor C_{22}.

$\mathbf{C_{22}}$	C_{11}	C_{13}	C_{15}	W_{22}
C_{11}	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.1,0.8,0.7,-0.9,-0.2,-0.1\rangle$	$1/\langle 0.9,0.1,0.1,-0.4,-0.8,-0.9\rangle$	0.217
C_{13}	$1/\langle 0.1,0.8,0.7,-0.9,-0.2,-0.1\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	0.447
$\mathbf{C_{15}}$	$\langle 0.9,0.1,0.1,-0.4,-0.8,-0.9\rangle$	$1/\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	0.337

Table 16. Interdependencies Matrix of Factor C_{23}.

$\mathbf{C_{23}}$	C_{11}	C_{13}	$\mathbf{C_{15}}$	$\mathbf{C_{21}}$	W_{22}
C_{11}	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	$1/\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	0.182
C_{13}	$1/\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$1/\langle 0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	$\langle 0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	0.313
$\mathbf{C_{15}}$	$1/\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	$\langle 0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$1/\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	0.247
$\mathbf{C_{21}}$	$\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	$1/\langle 0.4,0.2,0.7,-0.5,-0.2,-0.1\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	0.258

Table 17. Interdependencies Matrix of Factor C_{31}.

C_{31}	$\mathbf{C_{21}}$	C_{23}	C_{32}	W_{22}
$\mathbf{C_{21}}$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$1/\langle 0.1,0.8,0.7,-0.9,-0.2,-0.1\rangle$	$\langle 0.9,0.1,0.1,-0.4,-0.8,-0.9\rangle$	0.467
C_{23}	$\langle 0.1,0.8,0.7,-0.9,-0.2,-0.1\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$1/\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	0.227
C_{32}	$1/\langle 0.9,0.1,0.1,-0.4,-0.8,-0.9\rangle$	$\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	0.306

Table 18. Interdependencies Matrix of Factor C_{32}.

C_{32}	C_{14}	C_{21}	C_{31}	W_{22}
C_{14}	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$1/\langle 0.1,0.8,0.7,-0.9,-0.2,-0.1\rangle$	$\langle 0.9,0.1,0.1,-0.4,-0.8,-0.9\rangle$	0.467
C_{21}	$\langle 0.1,0.8,0.7,-0.9,-0.2,-0.1\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	$1/\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	0.227
C_{31}	$1/\langle 0.9,0.1,0.1,-0.4,-0.8,-0.9\rangle$	$\langle 0.8,0.5,0.5,-0.3,-0.8,-0.8\rangle$	$\langle 0.5,0.5,0.5,-0.5,-0.5,-0.5\rangle$	0.306

Table 19. ANP Final Weight for Criteria.

W_{22}	W_{11}	W_{12}	W_{13}	W_{14}	W_{15}	W_{21}	W_{22}	W_{23}	W_{31}	W_{32}	W_{21}	Total Criteria Weight ($W_{criteria}$)
W_{11}	0	0.458	0	0	0.386	0	0.217	0.182	0	0	0.096	0.113
W_{12}	0.217	0	0.162	0	0	0	0	0	0	0	0.088	0.035
W_{13}	0	0	0	0.467	0.283	0	0.447	0.313	0	0	0.088	0.138
W_{14}	0	0	0	0	0	0	0	0	0	0.467	0.098	0.082
W_{15}	0	0	0	0	0	0	0.337	0.247	0	0	0.100	0.049
W_{21}	0	0.288	0.312	0.227	0	0	0	0.258	0.467	0.227	0.115	0.173
W_{22}	0.447	0	0.269	0	0.331	0.182	0	0	0	0	0.066	0.121
W_{23}	0	0	0.256	0	0	0.313	0	0	0.227	0	0.109	0.073
W_{31}	0.337	0	0	0	0	0.247	0	0	0	0.306	0.063	0.115
W_{32}	0	0.254	0	0.306	0	0.258	0	0	0.306	0	0.176	0.101

Step 10: Aggregation of the Criteria:

The weighted overlay in ArcGIS was used to combine the different geospatial layers for the modelling criteria. The study area's final suitability scores were calculated by reclassifying the weighted overlay scores into four classes, with the areas corresponding to the exclusionary areas being graded as "not-suitable". As seen in fig. (4).

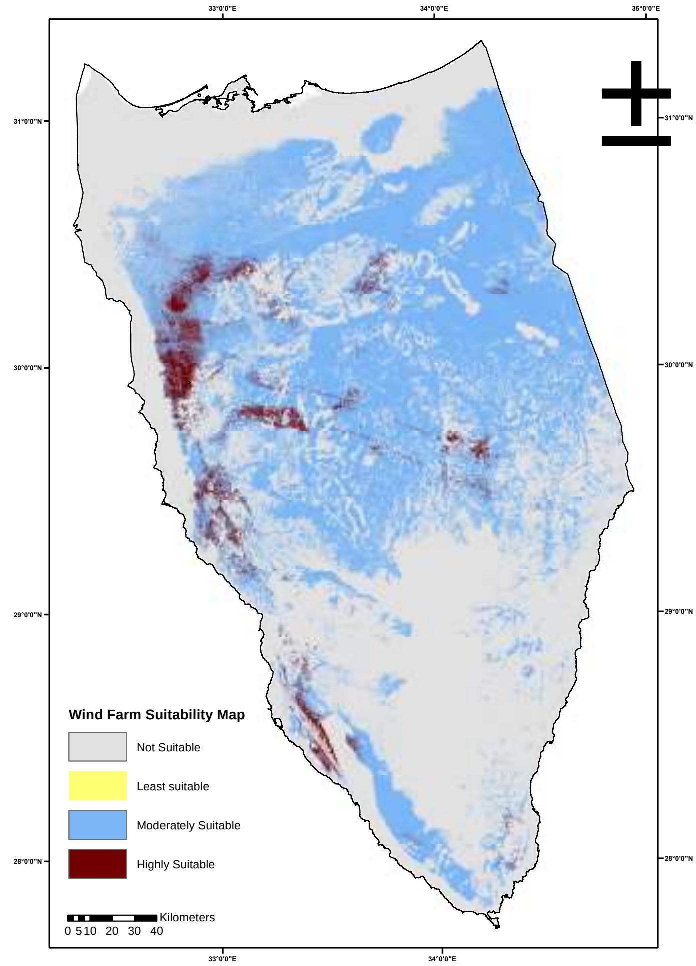


Figure 4. Suitability Maps of the Wind Farms.

6. Conclusion

This paper introduces a new model for mapping potential wind energy zones in Sinai Peninsula in Egypt that combines remote sensing data and a spatial decision support model. we use bipolar neutrosophic numbers to explain the values of attributes to accommodate the shortage of judgement knowledge .

The selection of suitable sites for wind farms in Sinai Peninsula is based on a number of interrelated factors of geography, climate and land use-land cover. For studying such factors, remote sensing (ASTER) and GIS techniques were used and a Spatial Multicriteria Decision Making (SMDM) model was designed.

The creation of a spatial decision model resulted from the incorporation of interpreted data obtained from a series of layers regarding natural and environmental characteristics, as well as Scio-economic. The research resulted in a suitability index map with various suitable zones for grid-connected wind power plant construction.

It is concluded that Spatial Multicriteria Decision Making model managed to solve the site selection problem and fulfill the objective of the study. It considered the most effective criteria, i.e., natural, environmental and Scio-economic, and their relative importance in the decision making. In addition, to accommodate missing details, the bipolar neutrosophic set is included in the specialist committee judgement. Such decisions support tool studied need more attention from both researchers and decision makers.

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