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A hybrid Model Using MCDM Methods and Bipolar Neutrosophic Sets for Select Optimal Wind Turbine: Case Study in Egypt

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Abstract: The wind turbine selection problem is important for countries under change of climate and global warming. The importance wind turbine has increased due to toward countries used the renewable energy. The information of selection wind turbines is often vague and imprecise. Therefore, this paper develops a methodology for wind turbines selection problem based on neutrosophic information. Bipolar neutrosophic sets (BNSs) is a very common tool for performing potentially uncertain information provided by experts and decision makers. So, the BNSs is a useful for dealing with uncertain complex situations. The wind turbine is contain the different and conflict criteria. Thus, the concept of multi-criteria decision making (MCDM) is used. This paper used MCDM method for selection wind turbine problem. First. Used the entropy weight to calculate the weights of criteria. Then the Weighted sum method (WSM), visekriterijumsko kompromisno rangiranje (VIKOR), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Evaluation based on Distance from Average Solution (EDAS) are used to select best turbine. The case study in Egypt is provided. The comparative analysis is done to test the reliability of the proposed methodology. Finally the sensitivity analysis is performed.

Keywords: Wind Turbine Selection, MCDM, Entropy Weight, TOPSIS, EDAS, WSM, VICKOR

1. Introduction

Every day the global warming and change of climate are increased in the world. Consequence this, the awareness of the world are increased toward saving the ecosphere and going to use the fossil fuel [1]. The countries that depend on the energy from fossil fuel are converting to a renewable energy. In recent years, a new resources of energy is explored due to diminution of fossil fuel. There are many sources of renewable energy for instance, wind, wave, solar and others.

To beat the global warming, the wind energy is introduced as one of many plans[2]. Every day the value of wind energy is increasing so, several states and countries are gain money by using the wind power [3]. By the sun and unbalance abhorring of the land and sea with variance of pressure the wind energy is produced. In recent years, with quick growth, the substitute of the traditional energy systems is the wind energy[4]. The most vital parts of theses energy system are wind turbines. The energy of electricity is produced in wind turbines by converting energy of motion of wind. So, choice the wind turbines is a critical work and must be precise for long term processes.

Many countries is seeking to build the wind farms due to have many advantages like creating many jobs through increasing the attract investment by deployment the economic, the security of energy is increased, the quality of air is enhanced, the emissions of co_2 is reduced, the dependence on the using imported fuel is decreased and the prices of power will stable. There are three costs are incurred by wind farms to produce electricity. These costs are include: capital costs that contain the building power plant costs, the costs of running that contain the costs of operations and maintenance of the wind farm and the costs of financing that include the costs of running and constructing the wind farm. The cost of capital is very great. The choice best wind turbine is a high weight as a wind turbine cost make up the mainstream of the total cost for wind farm project. The selection an appropriate wind turbine that include many of problems such as effective and efficient wind farm development, maximum energy output and efficient wind farm design. So in this paper take into considerations these factors.

In the previous studies, the researchers are proposed many of techniques for selection wind turbines problem for instance heuristics, Meta heuristics and models of probability [5]. Though, these approaches have many confines and disadvantages[6]. The decision model has limitations, one of these limitations it is simple due to has one criterion[7]. Though, the problem of choice wind turbines has several different conflict criteria[8]. So, the multi criteria decision making (MCDM) is the best solution to this problem. The methods of MCDM is a preferable with numerous criteria of wind turbines and each criterion is conflict with other[9].

The criteria of wind turbines find in many units and scale. But must put all criteria in one unit with less magnitude[6]. MCDM approaches are used with the fuzzy theory to overcome this difficulties[10]. Using the fuzzy theory with the truth and false value[11]. But the fuzzy has limitations that not take into considerations the indeterminacy value although fuzzy sets has many generations such as intuitionistic fuzzy sets and hesitant fuzzy sets [12]. To overcome these limitations the neutrosophic set is presented. Neutrosophic sets is generalization of fuzzy sets and introduced by. Florentin Smarandache [13, 14]. Neutrosophic sets is used in many fields like industry, healthcare and others [15]. It has truth, false and indeterminacy value. In this work use the MCDM methods with neutrosophic numbers to select the best wind turbines.

To select best wind turbines, needs a regular approaches due to this selection is a complex and difficult but it is vital and essential to wind farms. So, needs in this work to evolve approaches and methods to this problem to aid Egypt to build a new wind farm in government red sea and introduce best wind turbines for designing.

In this work, the criteria is collected from the literature and the weights of criteria is computed by entropy weight method[16]. The entropy weight method is not used in previous research with wind turbines. Experts and decision makers build the decision matrix between criteria and alternative by using linguistic term of neutrosophic number.

To rank the wind turbines the MCDM methods are proposed. In this paper proposed WSM, VIKOR, TOPSIS and EDAS methods with the bipolar neutrosophic numbers (BNNs) to select best alternative (turbine). The WSM is the simplest additive weighted method. It is most commonly used MCDM methods. It used in this paper to rank the wind turbine. The VIKOR method is a commonly MCDM method. It used to solve the problems of decision making with different and conflicting criteria. this method is used to rank the wind turbines. The TOPSIS method is a common MCDM methods. It is used to select best alternatives. This method solve the MCDM problems in different areas. It used in this paper to rank the wind turbines. The EDAS method is an effective and efficient to solve the problems with conflicting criteria. It used to rank the wind turbines.

With this kind of problem these four methods are not used before with other. So in this work integrate the entropy weight, WSM, VIKOR, TOPSIS and EDAS with the BNNs as an innovation to select best wind turbines to help the government of Egypt to build a new wind farm in the government red sea. This a MCDM model is used to rank the wind turbine by taking into account different criteria and turbines.

The rest of this paper was organized as follow: The literature review is presented in section 2. Section 3 presented the methodology of this paper. The case study is presented in section 4. The comparative analysis is performed in section 5. In section 6 the sensitivity analysis. Finally the conclusions of this study is presented in section 7.

2. Review of Literature

The position and importance of wind turbines is increased due to the several number of needs and usage of wind energy. Researcher have many works in technical structure and design the wind turbines due to it is the vital part to produce the wind energy [17]. Although, the works in selection wind turbines problem are relatively insufficient [18-20]

Rosales et al. compare wind turbines based on the energy cost using two variables hub height and total efficiency due to number of non-experts choose the wind turbines based on the commercial offers. The main drawbacks in their work dataset that signifies only a subclass of the total population of commercialized horizontal axis wind turbines [21]. Sedaghata et al. discuss a new strategy for the wind turbines selection problem. They depend on three variables the capacity, annual production of energy and electricity cost. The main results found that wind turbines with lower rated power will reduce the cost of electricity and wind turbines with greater rated power will produce greater capacity and annual production of energy. The main drawbacks of their study not used many of criteria they depend only three criteria [22] .

The selection wind turbine problem is contain the uncertainty information. So proposed the fuzzy theory to deal with uncertainty. Pang et al. proposed in their study fuzzy theory to overcome the uncertainty and vague information [23]. But the fuzzy theory has limitations. The main limitations of fuzzy theory not deal with indeterminacy value. So, the neutrosophic sets is proposed in this study to overcome the uncertainty information. The main advantage of neutrosophic sets that deal with the indeterminacy value. It has three value truth, indeterminacy and false [24]. The neutrosophic sets has many generalizations like Bipolar Neutrosophic Sets (BNSs). Abdel-Basset et al. proposed the BNSs for professional selection problem [25]. Broumi et al. proposed the BNSs for shortest path problem. [26] Based on this, no previous study used the BNSs for selection wind turbine problem. So in this paper proposed the BNSs for overcome the uncertainty information in selection wind turbine problem. Using concept the MCDM for dealing with different and conflict criteria.

The studies in wind turbines selections using MCDM methods is relatively few[9]. The analytical hierarchy process (AHP) approach is the commonly used in wind turbines selection problem[3, 20]. The AHP method has many advantage as build the pairwise comparison and check the consistency to test consistent the opinions of the decision makers. Also it has disadvantage as biased pairwise and complexity. In this study used the entropy weight method to calculate the weights of criteria. It is not used before in the previous study with the selection wind turbines problem. But used into another fields. Wang et al. used the entropy weight method with the Pythagorean fuzzy for valuation the express quality of service. The main limitation in their study that not into consideration the indeterminacy value [27]. Zeng et al. used the entropy weight method to sustainable supplier selection with single value neutrosophic sets [28]. Xiao et al. used the entropy weight method with fuzzy theory for assessment the urban taxi-carpooling matching schemes [29]. So in this study used the entropy weight method to calculate the weights of criteria due to has many advantage as deal with uncertainty, compute the degree of confusion and less entropy value can produce more of information.

There are many MCDM methods to calculate the best alternatives (wind turbines). WSM is one of the simplest and mostly widely used MCDM methods. Rehman and Khan used the WSM for selection best wind turbine. They used five criteria and eighteen turbines. They used the C++ program to perform simulation [1]. Yörükoğlu and Aydın used the MULTIMOORA method to select wind turbines[17].

VIKOR method is used to solve decision making problems with conflict and different units of criteria. The main advantage from this method that focus on the basic information as result this, reduce the computational complexity [30]. VIKOR method is not used in previous selection wind turbine problem. Abdel-Basset et al. used the VIKOR method for assessment the performance financial of manufacturing industries [31]. Li et al. used the VIKOR method for selection machine tool [32]. Krishankumar et al. used the VIKOR method for problem of personnel selection [33].

TOPSIS method is a common MCDM methods. It is used for calculate the best alternatives. It is used for solving MCDM problems in several areas. The main concept of TOPSIS is that the highest alternative rank should have the lower distance from the positive ideal solution [34]. The TOPSIS method is used in wind turbine selection problem. Supciller et al. used the TOPSIS method for determine the best wind turbine with case study in Turkey. They used the single value neutrosophic set with twenty one criteria [24]. Ahmet et al. used the AHP-TOPSIS to with hesitant fuzzy for assessment wind turbines. The main limitation sin their study that is not take into considerations the indeterminacy value [3].

EDAS method is also a MCDM methods. It is used for solving decision making problems and determine the best alternatives. It is easy and useful for applying to different conflicting criteria. The main rule for this method that is the best alternative is computed by shortness distance from the average solutions [34]. Supciller et al. used the EDAS method to select best turbine for a case study in Turkey [24]. Kahraman et al. used the EDAS method with the Intuitionistic fuzzy for selection solid waste disposal site problem [35].

So in this work discuss many of criteria that conflict with others for wind turbines selection problem. Used the entropy weight method to calculate the weights of criteria for the first time in this problem. Used the WSM, VIKOR, TOPSIS and EDAS to select best turbine. The VIKOR method is used the first time in selection wind turbine problem.

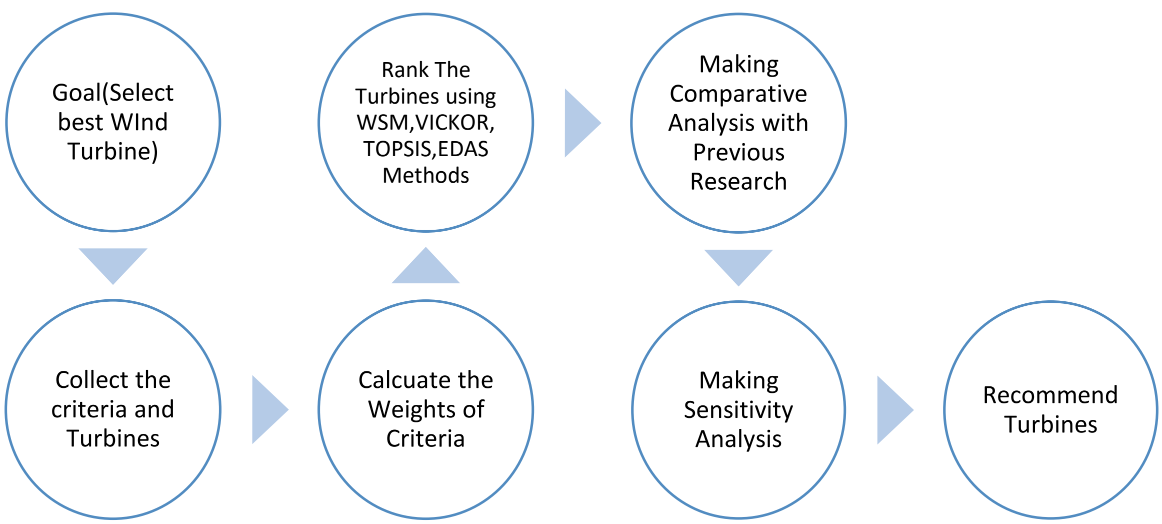

Fig 1. The framework for this study

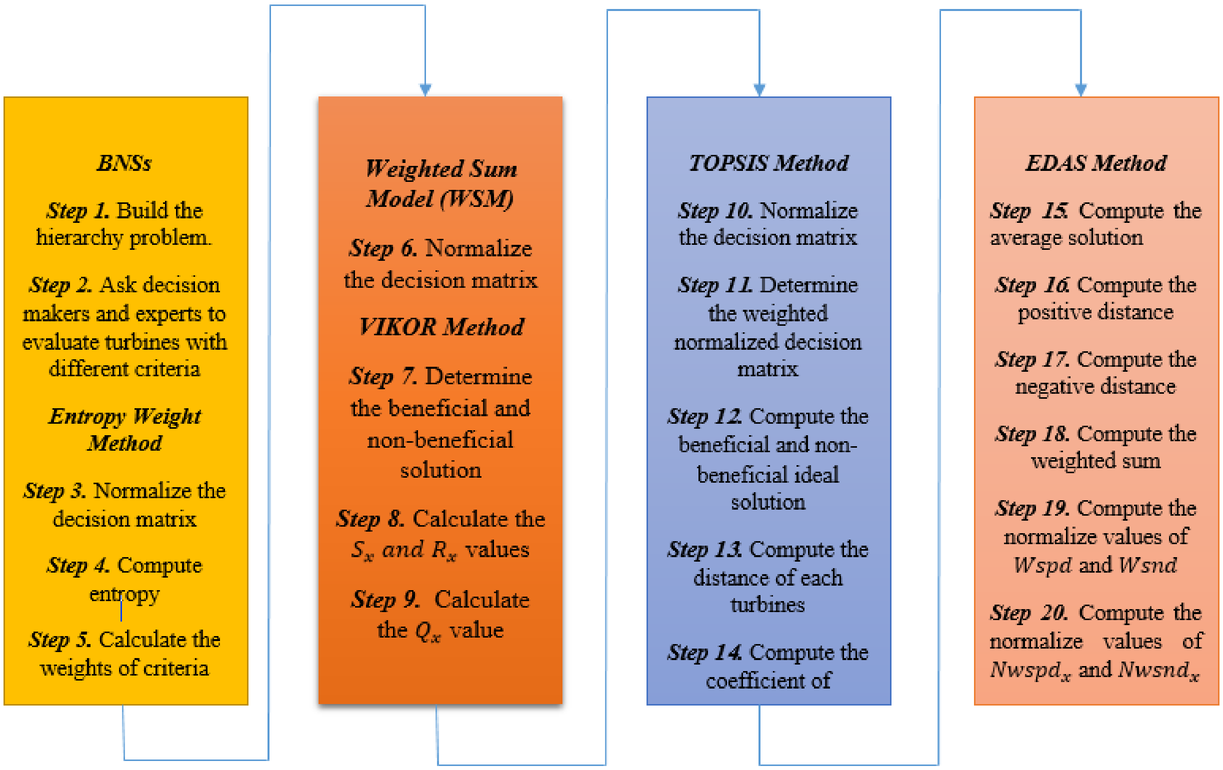

Fig 2. The methodology for this paper

3. Methodology

This paper introduced the integrate BNSs with a MCDM entropy weight method for selection best wind turbine to build a new farm in Egypt. The entropy weight method is used to determine the weights of all criteria. Then used the WSM, VICKOR, TOPSIS and EDAS to rank the wind turbines. Then the best wind turbine is recommended. Fig 1. Show the framework for this study. .Fig 2. Show the methodology for this study. The steps of methodology is presented as follow:

3.1 Bipolar Neutrosophic Sets (BNSs)

In this sub section, suggested linguistic information of BNNs and the functions of score, accuracy and certainty. Bipolar Neutrosophic sets are suggested to solve the MCDM problems. BNNs are consist from Truth (T^+, T^-), Indeterminacy (I^+, I^-) and False (F^+, F^-) where T^+, I^+, F^+ [0,1] are positive and $T^-, I^-, F^- \rightarrow$ [0,1] are negative. Table 1 show the Linguistic variable and scale of BNNs. Where Very perfect (linguistic term) is the highest value and very Bad (linguistic term) is the lowest value. The score, accuracy and certainty functions are shown in the following Eqs. (1, 2, 3)[25]:

$$\tilde{R}(\widetilde{C_1}) = (T_1^+ + 1 - I_1^+ - F_1^+ + 1 + T_1^- - I_1^- - F_1^-)/6 \quad (1)$$

$$\tilde{C}(\widetilde{C_1}) = (T_1^+ - F_1^+ + T_1^- - F_1^-) \quad (2)$$

$$\tilde{E}(\widetilde{C_1}) = (T_1^+ + F_1^-) \quad (3)$$

The steps of BNSs is presented as follow:

Step 1. Build the hierarchy problem.

The main goal form this study that select best wind turbine. Then collect the main and sub criteria, where u refers to the criteria ($u = 1, 2, 3, 4, \ldots\ldots x$) and x refers to number of criteria. Then determine wind turbines (Alternatives), where v refers to turbines ($v = 1,2,3,, \ldots\ldots y$) and y refers to number of turbines.

Step 2. Ask decision makers and experts to evaluate turbines with different criteria.

Building the decision matrix between criteria turbines with the opinions of experts by using scale of BNNs in Table 1 by Eq. (4). Then Deneutrosophic the BNNs by Eq. (1) to obtain one value instead of six value. Then aggregate the decision matrix of opinions experts into one matrix by Eqs (5, 6).

$$P^D = \begin{bmatrix} P_{11}^D & \cdots & P_{1u}^D \\ \vdots & \ddots & \vdots \\ P_{v1}^D & \cdots & P_{vu}^D \end{bmatrix} \quad (4)$$

Where, D indicates to number of experts.

$$P_{xy} = \frac{\sum_{D=1}^{D} P_{uv}}{D} \quad (5)$$

$$P = \begin{bmatrix} P_{11} & \cdots & P_{1x} \\ \vdots & \ddots & \vdots \\ P_{y1} & \cdots & P_{vu} \end{bmatrix} \quad (6)$$

3.2 *Proposed The MCDM Methods*

The following steps for entropy, WSM, VIKOR, TOPSIS and EDAS methods.

3.2.1 *Entropy Weight Method*

Entropy weight method is used to determine the weights of criteria. The following steps show the entropy weight[36]:

Step 3. Normalize the decision matrix

Start with the decision matrix with aggregated the opinion of experts. Then normalize the aggregation decision matrix using Eq. (7).

$$N_{xy} = \frac{P_{xy}}{\sum_{y=1}^{v} P_{xy}} \quad (7)$$

Step 4. Compute entropy

The entropy is computed by the multiply the ln of normalized decision matrix by normalized decision matrix then compute the summation of it. Finally multiply this summation by the negative L by using Eq. (8):

$$O_x = -L \sum_{y=1}^{v} N_{xy} \ln N_{xy} \quad (8)$$

Where L = $1/\ln(y)$

Step 5. Calculate the weights of criteria using Eq. (9)

$$W_x = \frac{1-O_x}{\sum_{y=1}^{u}(1-O_x)} \quad (9)$$

3.2.2 ***Weighted Sum Model (WSM)***

Step 6. Normalize the decision matrix***[36]***

Start with the aggregation decision matrix and multiply each weight by the value of decision matrix and then obtain the normalization matrix by using Eq. (10). Then ranking the turbines descanting according to normalize value

$$Z_x = \sum_{y=1}^{u} W_x P_{xy} \quad (10)$$

3.2.3 **VIseKriterijumska Optimizacija I Kompromisno Resenje** ***(VIKOR)***

VIKOR method is used to rank turbines with different conflict criteria. The following steps of VIKOR method [36].

Step 7. Determine the beneficial-ideal solution (B^+) and non-beneficial-ideal solution (B^-) using Eqs. (11, 12)

$$B_x^+ = \max_x P_{xy} \text{ for Positive criteria and } B_x^+ = \min_x P_{xy} \text{ for negative criteria} \quad (11)$$

$$B_x^- = \min_x P_{xy} \text{ for Positive criteria and } B_x^- = \max_x P_{xy} \text{ for negative criteria} \quad (12)$$

Step 8. Calculate the S_x *and* R_x values using Eqs. (13, 14)

$$\mathrm{S_x} = \sum_{y=1}^{v} (W_y * \frac{B_x^+ - P_{xy}}{B_x^+ - B_x^-}) \quad (13)$$

$$\mathrm{R_x} = \max_y (W_y * \frac{B_x^+ - P_{xy}}{B_x^+ - B_x^-}) \quad (14)$$

Step 9. Calculate the Q_x value using Eq. (15). Then rank the turbines ascending to value of Q_x.

$$Q_x = h\left(\frac{\mathrm{S_x} - \min_x \mathrm{S_x}}{\max_x \mathrm{S_x} - \min_x \mathrm{S_x}}\right) + (1-h)\left(\frac{\mathrm{R_x} - \min_x \mathrm{R_x}}{\max_x \mathrm{R_x} - \min_x \mathrm{R_x}}\right) \quad (15)$$

Value of h refers to highest group utility of strategy weight and (1-h) refers to individual regret of weight. Usually, the value of h is equal to 0.5 and the value of h can be range from 0 to 1.

4.2.3 Technique for Order Performance by Similarity to Ideal Solution (TOPSIS)

The steps of TOPSIS method is presented as follow[36]:

Step 10. Normalize the decision matrix

Start with the aggregation decision matrix between criteria and turbines. Then normalize the decision matrix using Eq. (16)

$$N_{xy} = \frac{P_{xy}}{\sqrt{\sum_{y=1}^{v} P_{xy}^2}} \quad (16)$$

Step 11. Determine the weighted normalized decision matrix

Multiply the weights of criteria by the normalize decision matrix to calculate the weighted normalized decision matrix using Eq. (17).

$$I_{xy} = N_{xy} W_y \quad (17)$$

Step 12. Compute the beneficial ideal solution (f^+) and non-beneficial ideal solution (f^-) using Eqs. (18, 19)

$$f_x^+ = \max_x P_{xy} \text{ for Positive criteria and } f_x^+ = \min_x P_{xy} \text{ for negative criteria} \quad (18)$$

$$f_x^- = \min_x P_{xy} \text{ for Positive criteria and } f_x^- = \max_x P_{xy} \text{ for negative criteria} \quad (19)$$

Step 13. Compute the distance of each turbines from beneficial and non-beneficial ideal solution by using Eqs. (20, 21)

$A_y^+ = \sum_x^u (I_{xy} - f_x^+)^2$ for positive criteria (20)

$A_y^- = \sum_x^u (I_{xy} - f_x^-)^2$ for cost criteria (21)

Step 14. Compute the coefficient of closeness

From the distance of each turbine, calculate the value of closeness coefficient using Eq. (22). Then rank turbine according the descending order of value closeness coefficient.

$$\mathrm{G_y} = \frac{A_y^-}{A_y^+ + A_y^-} \quad (22)$$

4.2.4 Evaluation based on Distance from Average Solution (EDAS)

The steps of EDAS method is presented as follow[24]:

Step 15. Compute the average solution

Start with the aggregation decision matrix. Then compute the average solution by divide the value of decision matrix by the number of turbines using Eq. (23)

$$vg_{\mathrm{y}} = \frac{\sum_{x=1}^{b} P_{xy}}{b} \quad (23)$$

Step 16. From the average solution compute the positive distance for positive and cost criteria using Eqs. (24,25)

$\mathrm{Pos}_{xy}^+ = \frac{\max(0,(p_{xy} - vg_{\mathrm{y}}))}{vg_{\mathrm{y}}}$ For positive criteria (24)

$\mathrm{Pos}_{xy}^- = \frac{\max(0,(vg_{\mathrm{y}} - p_{xy}))}{vg_{\mathrm{y}}}$ For cost criteria (25)

Step 17. From the average solution compute the negative distance for positive and cost criteria using Eqs. (26,27)

$\mathrm{Neg}_{xy}^+ = \frac{\max(0,(vg_{\mathrm{y}} - p_{xy}))}{vg_{\mathrm{y}}}$ For positive criteria (26)

$\mathrm{Neg}_{xy}^- = \frac{\max(0,(p_{xy} - vg_{\mathrm{y}}))}{vg_{\mathrm{y}}}$ For cost criteria (27)

Step 18. Compute the weighted sum of positive distance

From the positive distance for positive and negative criteria multiply the weight of criteria by the positive distance and compute the sum of this multiplication using Eqs. (28, 29)

$$Wspd_x = \sum_{y=1}^{v} W_y \, \mathrm{Pos_{xy}} \quad (28)$$

$$Wsnd_x = \sum_{y=1}^{v} W_y \, \mathrm{Neg_{xy}} \quad (29)$$

Step 19. Compute the normalize values of $Wspd$ and $Wsnd$ using Eqs. (30,31)

$$Nwspd_x = \frac{Wspd_x}{\max(Wspd_x)} \quad (30)$$

$$Nwsnd_x = 1 - \frac{Wsnd_x}{\max(Wsnd_x)} \quad (31)$$

Step 20. Compute the normalize values of $Nwspd_x$ and $Nwsnd_x$

After compute the value of nor_x rank turbines according descending order of value nor_x using Eq. (32)

$$nor_x = 0.5 * (Nwspd_x + Nwsnd_x) \quad (32)$$

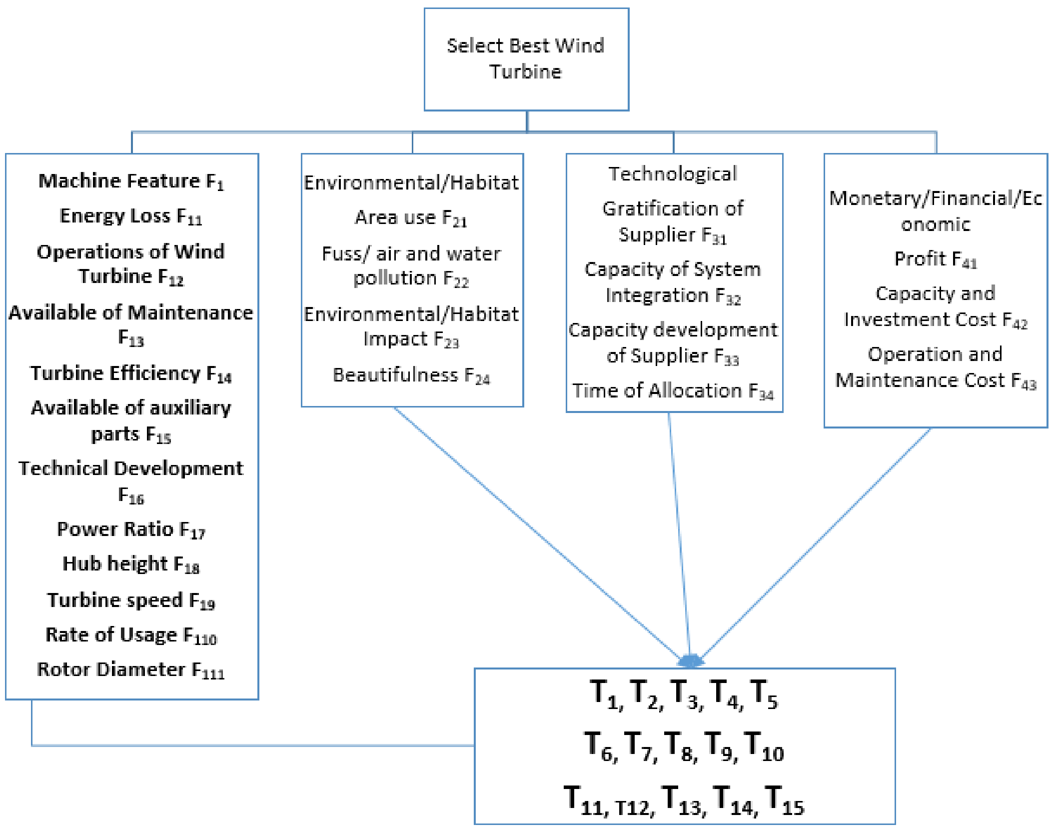

Fig 3. The structure between criteria, sub criteria and turbines

4. Case Study

Egypt vision in 2030 depend on decreasing using the fossil fuels and increasing using the renewable energy. One of the important renewable energy is wind turbine. The choice the wind turbines is the important issue. So in this study choice the best wind turbine to help Egypt vision to build different wind farms.

Start this study by collect a collection of decision makers and experts. This collection includes of four people working in companies of renewable energy in Egypt. Two of this group working as a manger on renewable energy. The other two experts working as mechanical engineering. Two of them have a PHD degree in engineering and others have a master degree in engineering. The all of these experts and decision makers have a weighty degree in expertise. All these decision makers have the same weight of degree. Making interview with these decision makers for recognizing the criteria and alternatives with their opinions.

Making into considerations the different types of wind turbines. The fifteen alternatives (wind turbines) are selected. T_1 V164-9.5MW, T_2 SG 8.0-167 DD, T_3 GW154 6.7MW, T_4 Senvion 6.2M152, T_5 GE Haliade 150-6MW, T_6 Ming Yang SCD 6.0, T_7 Doosan WindS500,T_8 Hitachi HTW5.2-136, T_9 H151-5.0MW, T_{10} AD 5-135, T_{11} E-126 7.580, T_{12} Haliade-X, T_{13} SG 11.0-193 DD Flex, T_{14} D10000-185, T_{15} V164-10.0. The criteria and sub criteria are identified and collected based on the survey of literature. The opinions of decision makers and experts is presented based on the BNSs. Fig 3 show the criteria, sub criteria and alternatives for this study. The criteria is divided to positive and negative (cost) criteria. The F_{11}, F_{21}, F_{22}, F_{23}, F_{34}, F_{42}, F_{43} criteria are negative and the rest of criteria are positive.

The entropy weight method is used to compute the weights of criteria. Then used the WSM, VIKOR, TOPSIS and EDAS methods are used to rank the turbines (alternatives).

4.1 Computing the weights of criteria by entropy weight method

The group of decision makers and experts assets the criteria to compute the importance of the criteria by entropy weight method. First the linguistic term is introduced to four decision makers to build the decision matrix. Then, replace the linguistic term by BNNs in Table 1. The opinions of four experts is used to build the decision matrix by using Eq. (4). Then, convert the BNNs into the crisp value (one value instead of six value of BNNs) by using Eq. (1). Hence, have the four decision matrix so, need to aggregate it into one matrix by using Eqs. (5,6) in Table 2.

The steps of entropy weight method is applied in next stage. Start with the aggregated decision matrix between the criteria and turbines (alternatives). First normalize the aggregated decision matrix by using

Eq. (7). Then, compute the entropy by using Eq. (8). Finally the weights of main and sub criteria is computed by using Eq. (8). In Table 3.the ranking and weights of main and sub criteria.

The results of entropy weight show the importance of the criteria and sub criteria between other. The Machine feature (F_1) is the highest important main criteria equal 0.42302 then Technological (F_3) is after machine feature with value 0.19949 then, importance of Monetary criteria (F_4) is lower than technological criteria, then the Habitat criteria (F_2) is the lowest criteria in four main criteria.

The results of sub criteria show that the operation and maintenance cost (F_{43}) with value 0.08431 is the highest weight in sub criteria and the technical development (F_{16}) with value 0.02093 is the lowest weight in sub criteria.

Table 1. Scale of BNSs.

Linguistic term	**BNNs**	
Linguistic Variable	**T_1^+,I_1^+,F_1^+,**	**T_1^-,I_1^-,F_1^-**
Very Bad	<0.1,0.9,0.8,	-0.8,-0.3,-0.1>
Bad	<0.3,0.5,0.7,	-0.6,-0.4,-0.4>
Medium	<0.45,0.45,0.5,	-0.45,-0.5.-0.45>
Perfect	<0.7,0.3,0.4,	-0.3,-0.6,-0.8>
Very Perfect	<0.9,0.1,0.2,	-0.2,-0.7,-0.9>

Table 2. The aggregated decision matrix between criteria and turbines (alternatives)

Criteria/turbines	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}	F_{16}	F_{17}	F_{18}	F_{19}	F_{110}	F_{111}
T_1	0.683	0.500	0.383	0.683	0.683	0.833	0.500	0.683	0.500	0.500	0.683
T_2	0.833	0.833	0.683	0.500	0.683	0.833	0.383	0.683	0.683	0.500	0.833
T_3	0.683	0.383	0.833	0.683	0.500	0.833	0.383	0.833	0.683	0.683	0.833
T_4	0.383	0.683	0.833	0.383	0.683	0.683	0.167	0.833	0.833	0.833	0.833
T_5	0.683	0.833	0.383	0.683	0.383	0.683	0.683	0.683	0.833	0.833	0.683
T_6	0.833	0.683	0.383	0.383	0.383	0.500	0.383	0.383	0.683	0.683	0.383
T_7	0.833	0.833	0.167	0.683	0.833	0.683	0.167	0.833	0.383	0.833	0.167
T_8	0.833	0.383	0.683	0.383	0.833	0.383	0.683	0.683	0.683	0.383	0.383
T_9	0.833	0.167	0.683	0.683	0.383	0.833	0.833	0.683	0.500	0.167	0.833
T_{10}	0.683	0.383	0.383	0.683	0.683	0.833	0.383	0.383	0.500	0.683	0.683
T_{11}	0.833	0.683	0.683	0.833	0.383	0.683	0.167	0.500	0.683	0.833	0.383
T_{12}	0.833	0.683	0.383	0.683	0.833	0.383	0.383	0.500	0.833	0.383	0.500
T_{13}	0.683	0.833	0.167	0.383	0.683	0.683	0.833	0.833	0.683	0.383	0.500
T_{14}	0.683	0.383	0.683	0.833	0.383	0.167	0.683	0.683	0.683	0.683	0.683
T_{15}	0.683	0.383	0.683	0.383	0.683	0.833	0.383	0.833	0.833	0.683	0.683
Criteria/turbines	F_{21}	F_{22}	F_{23}	F_{24}	F_{31}	F_{32}	F_{33}	F_{34}	F_{41}	F_{42}	F_{43}
T_1	0.500	0.500	0.683	0.500	0.833	0.683	0.500	0.383	0.683	0.500	0.500
T_2	0.500	0.383	0.833	0.500	0.683	0.833	0.383	0.500	0.683	0.683	0.383
T_3	0.683	0.383	0.683	0.683	0.383	0.833	0.383	0.167	0.833	0.683	0.383

T_4	0.383	0.833	0.683	0.683	0.167	0.683	0.167	0.683	0.833	0.383	0.167
T_5	0.167	0.683	0.383	0.833	0.383	0.383	0.683	0.833	0.500	0.167	0.167
T_6	0.383	0.383	0.383	0.833	0.683	0.383	0.683	0.683	0.500	0.383	0.683
T_7	0.683	0.833	0.167	0.833	0.683	0.167	0.683	0.683	0.833	0.683	0.683
T_8	0.683	0.383	0.167	0.683	0.500	0.383	0.833	0.500	0.383	0.833	0.833
T_9	0.683	0.683	0.683	0.683	0.500	0.683	0.833	0.500	0.167	0.833	0.833
T_{10}	0.833	0.383	0.683	0.500	0.683	0.683	0.500	0.683	0.683	0.500	0.833
T_{11}	0.383	0.833	0.500	0.500	0.683	0.833	0.500	0.683	0.683	0.500	0.383
T_{12}	0.383	0.683	0.500	0.383	0.167	0.833	0.500	0.833	0.833	0.683	0.383
T_{13}	0.500	0.383	0.683	0.167	0.383	0.683	0.683	0.383	0.500	0.683	0.167
T_{14}	0.500	0.833	0.833	0.383	0.500	0.683	0.683	0.167	0.500	0.833	0.167
T_{15}	0.683	0.683	0.683	0.683	0.683	0.167	0.833	0.500	0.683	0.683	0.683

Table 3. Final weights and ranking for the main and sub-criteria.

Main criteria	Weights	Rank	Sub-criteria	Weights	Rank
Machine Feature F_1	0.423017	1	Energy Loss F_{11}	0.021954	1
			Operations of Wind Turbine F_{12}	0.049721	8
			Available of Maintenance F_{13}	0.030774	21
			Turbine Efficiency F_{14}	0.042039	15
			Available of auxiliary parts F_{15}	0.031543	20
			Technical Development F_{16}	0.020927	22
			Power Ratio F_{17}	0.052603	6
			Hub height F_{18}	0.041303	16
			Turbine speed F_{19}	0.039383	17
			Rate of Usage F_{110}	0.049055	9
			Rotor Diameter F_{111}	0.043716	14
Environmental/Habitat F_2	0.18805	4	Area use F_{21}	0.048228	10
			Fuss/ air and water pollution F_{22}	0.03899	19
			Environmental/Habitat Impact F_{23}	0.053389	5
			Beautifulness F_{24}	0.047438	11
Technological F_3	0.199494	2	Gratification of Supplier F_{31}	0.062704	3
			Capacity of System Integration F_{32}	0.039025	18
			Capacity development of Supplier F_{33}	0.051427	7
			Time of Allocation F_{34}	0.046337	12
Monetary F_4	0.189444	3	Profit F_{41}	0.06014	4
			Capacity and Investment Cost F_{42}	0.044995	13
			Operation and Maintenance Cost F_{43}	0.084309	2

4.2 Rank Turbines

The wind turbines is ranked by the SWM, VIKOR, TOPSIS, EDAS methods. First Apply the WSM method.

The WSM is applied to rank wind turbines. Start with the aggregated decision matrix in Table 2. Then applied Eq. (10) to obtain final rank by multiply the weights of criteria by the value of aggregated decision matrix. The rank wind turbines by WSM method is presented in Table 4.

The results of WSM method show that T_9 is the highest rank with value 0.6126 and T_6 is the lowest rank with value 0.50064.

Table 4. The rank of turbines by WSM method

Turbines/Rank	Values	Rank	Total Points
T_1	0.594988	T_9	12
T_2	0.564966	T_7	8
T_3	0.580817	T_{10}	10
T_4	0.538728	T_1	3
T_5	0.555143	T_{15}	6
T_6	0.500635	T_3	1
T_7	0.603511	T_{13}	14
T_8	0.557474	T_2	7
T_9	0.612693	T_8	15
T_{10}	0.600935	T_5	13
T_{11}	0.549546	T_{11}	5
T_{12}	0.541628	T_{12}	4
T_{13}	0.571428	T_4	9
T_{14}	0.502519	T_{14}	2
T_{15}	0.592822	T_6	11

The second method (VIKOR) is applied to rank the turbines. First start with the aggregated decision matrix in Table 2. Then compute the beneficial-ideal solution (B^+) and non-beneficial-ideal solution (B^-) for positive and negative criteria by using Eqs. (11,12). Then the value of S_x is computed by using Eq. (13). Then compute the value of R_x by using Eq. (14). Finally applying Eq. (15) to compute the value of Q_x. Based on this, the rank of turbines is ordered ascending by value of Q_x. Table 5 presented the values of S_x, R_x, Q_x and ranking of turbines.

The results from applying the VIKOR method show that the T_2 is the highest rank with value 0.12725 and the T_9 is the lowest rank with value 1.

Table 5. The values of S_x, R_x, Q_x and rank of turbines by VIKOR method

Turbines/Rank	S_x	R_x	Q_x	Rank	Total Points
T_1	0.54934	0.066592	0.698403	T_2	4
T_2	0.40505	0.047397	0.127254	T_5	15

T_3	0.451533	0.04898	0.250675	T_4	11
T_4	0.353708	0.062704	0.215514	T_7	13
T_5	0.426901	0.046337	0.161515	T_3	14
T_6	0.443595	0.073311	0.553539	T_{14}	7
T_7	0.454352	0.047653	0.239425	T_{13}	12
T_8	0.489558	0.07881	0.727372	T_{11}	3
T_9	0.580291	0.084309	1	T_6	1
T_{10}	0.533824	0.07209	0.736572	T_{12}	2
T_{11}	0.515349	0.052603	0.4392	T_{15}	8
T_{12}	0.513857	0.062704	0.568914	T_1	6
T_{13}	0.46983	0.053389	0.349105	T_8	9
T_{14}	0.461978	0.051427	0.305942	T_{10}	10
T_{15}	0.548904	0.066592	0.697443	T_9	5

The third method (TOPSIS) is applied to rank turbines. Start with the combined decision matrix in Table 2. Then compute the normalized decision matrix by using Eq. (16). From the normalized decision matrix the Eq. (17) is applied to compute the weighted normalized decision matrix. Then compute the value of beneficial-ideal solution and non-beneficial-ideal solution for positive and negative criteria by using Eqs. (18,19). Then Applying Eqs. (20,21) to compute the distance of each turbine from beneficial and non-beneficial for positive and negative criteria. Finally Applying Eq. (22) for the compute the value of coefficient closeness G_y. The rank of turbines is computed descending by the value of G_y. In Table 6 the values of $A_y^+, A_y^- G_y$ and rank of turbines is presented.

The results of TOPSIS method show that the T_2 is the highest rank with value 0.6248 and T_9 is the lowest rank with value 0.4185.

Table 6. The values of $A_y^+, A_y^- G_y$ rank of turbines by TOPSIS method

Turbines/Rank	A_y^+	A_y^-	G_y	Rank	Total Points
T_1	0.031261	0.027524	0.468217	T_2	4
T_2	0.021399	0.035644	0.624863	T_4	15
T_3	0.023555	0.032831	0.582246	T_5	12
T_4	0.025083	0.037006	0.596013	T_3	14
T_5	0.023556	0.034485	0.594151	T_{14}	13
T_6	0.029447	0.031434	0.516321	T_7	8
T_7	0.026516	0.031088	0.539692	T_{11}	10
T_8	0.03366	0.027441	0.449111	T_6	2
T_9	0.036287	0.026118	0.418525	T_{13}	1
T_{10}	0.031895	0.028337	0.470463	T_{12}	5
T_{11}	0.028071	0.030586	0.521442	T_{10}	9

T_{12}	0.02889	0.028215	0.494095	T_1	6
T_{13}	0.02753	0.029085	0.513738	T_{15}	7
T_{14}	0.025255	0.033744	0.571948	T_8	11
T_{15}	0.030396	0.025705	0.458189	T_9	3

The fourth method (EDAS) is applied to obtain the rank of turbines. First start with aggregated decision matrix in Table 2. Then compute the average solution by using Eq. (23). Then compute the positive distance for positive and negative criteria by using Eqs. (24,25). Then compute the negative distance for positive and negative criteria by using Eqs. (26,27). Then compute the weighted sum of positive distance and negative distance by using Eqs. (28,29). Then compute the normalize value for weighted sum of positive ($NWSPd_x$) and negative distance ($NWSnd_x$) by using Eqs. (30,31) in Table 7. Finally compute the normalized value (Nor_x) for ($NWSPd_x, NWSnd_x$) by using Eqs. (32,33) in Table 7. The final rank is computed based on descending value of Nor_x in Table 7.

The results of EDAS method show that the T_4 is the highest rank with value 0.612422 and the T_3 is the lowest rank with value 0.4435.

Table 7. The values of $NWSPd_x, NWSnd_x, Nor_x$ and rank of turbines by EDAS method

Turbines/Rank	$NWSPd_x$	$NWSnd_x$	Nor_x	Rank	Total Points
T_1	0.44604	0.778805	0.612422	T_4	8
T_2	0.788992	0.445451	0.617222	T_9	10
T_3	0.510227	0.376734	0.44348	T_8	1
T_4	1	0.559512	0.779756	T_6	15
T_5	0.707808	0.501764	0.604786	T_{11}	7
T_6	0.70301	0.660142	0.681576	T_2	12
T_7	0.584757	0.534367	0.559562	T_{10}	5
T_8	0.607156	0.816269	0.711713	T_1	13
T_9	0.454275	1	0.727137	T_5	14
T_{10}	0.463	0.763534	0.613267	T_{14}	9
T_{11}	0.525765	0.716991	0.621378	T_7	11
T_{12}	0.402231	0.611706	0.506969	T_{12}	4
T_{13}	0.485332	0.508127	0.49673	T_{13}	3
T_{14}	0.599665	0.532189	0.565927	T_{15}	6
T_{15}	0.270496	0.62297	0.446733	T_3	2

Finally is this section make combination rank for four methods by total points. The concept of total points is applied as if the T_1 is the highest rank take 15 points and lowest rank take 1 points and so on. Table 8. Show the combined rank of four methods[36].

The results of combined four method show that the T_2 is the highest rank with highest total points and T_{12} is the lowest rank with lowest total points

Table 8. The combined rank of four methods.

Turbines/Rank	Total Points	Rank
T_1	28	T_2
T_2	48	T_4
T_3	34	T_7
T_4	45	T_5
T_5	40	T_3
T_6	28	T_{11}
T_7	41	T_9
T_8	25	T_{10}
T_9	31	T_{14}
T_{10}	29	T_1
T_{11}	33	T_6
T_{12}	20	T_{13}
T_{13}	28	T_8
T_{14}	29	T_{15}
T_{15}	21	T_{12}

5. Comparative analysis

In this section making the comparative analysis to test the reliability of this proposed methodology. Making two comparative analysis with SVNSs and Hesitant Fuzzy sets as follow:

5.1 Comparison by Single Valued Neutrosophic Sets

Aliye Ayca Supciller and Fatih Toprak[24] used SWARA, TOPSIS and EDAS methods to select best wind turbines. The SWARA method is used to calculate the weights of criteria. So, make comparison between SWARA and entropy weight method (method in this study).

The results of SWARA show that the F_1 = 0.4029, F_2 = 0.12241, F_3 = 0.30441, F_4 = 0.17069. Table 9. Show the weights of main criteria and Table 10. Show the weights of sub criteria by the entropy weight and

SWARA method. Results show that, in main criteria the highest weight by SWARA method is F_1 and the lowest weight is F_2, the highest weight by entropy weight method is F_1 and the lowest weight is F_2. In sub criteria the highest weights by SWARA is F_{16} and lowest weights is F_6 and highest weight by entropy is F_{22} and the lowest weight is F_6.

In ranking the turbine, make comparison between SVNSs TOPSIS and EDAS with BNSs TOPSIS, WSM, VIKOR and EDAS methods. By using the weights of SWARA and entropy weight methods the turbines is ranked. Table 11. Show the ranking by comparison study. Results show that, In SVNSs TOPSIS the T_2 is the highest rank and T_9 is the lowest rank. In SVNSs EDAS method, T_4 the highest rank and T_{13} is the lowest rank. In BNSs WSM method T_9 is the highest rank and T_6 is the lowest rank. In BNSs TOPSIS the highest rank is T_2 and the lowest rank is T_9. In BNSs VIKOR the T_2 is the highest rank and T_9 is the lowest rank. In BNSs T_4 is the highest rank and T_3 is the lowest rank.

Table 9. The weights of main criteria by entropy and SWARA methods.

Criteria/Rank	SWARA	Rank by SWARA method	Entropy weight	Rank by the entropy weight
F_1	0.40249	F_1	0.423017	F_1
F_2	0.12241	F_3	0.188045	F_3
F_3	0.30441	F_4	0.199494	F_4
F_4	0.17069	F_2	0.189444	F_2

Table 10. The rank weights of sub criteria by SWARA and entropy weight methods

Criteria/Rank	SWARA	Rank of SWARA	Entropy weight	Rank of entropy weight
F_{11}	0.002027	F_{16}	0.021954	F_{22}
F_{12}	0.098079	F_7	0.049721	F_{16}
F_{13}	0.003187	F_{22}	0.030774	F_{20}
F_{14}	0.022589	F_2	0.042039	F_{14}
F_{15}	0.005242	F_{14}	0.031543	F_7
F_{16}	0.001137	F_{10}	0.020927	F_{18}
F_{17}	0.150387	F_{18}	0.052603	F_2
F_{18}	0.012434	F_{20}	0.041303	F_{10}
F_{19}	0.009173	F_{11}	0.039383	F_{12}
F_{10}	0.061087	F_{12}	0.049055	F_{15}
F_{11}	0.037147	F_{19}	0.043716	F_{19}
F_{21}	0.031047	F_4	0.048228	F_{21}
F_{22}	0.004184	F_{21}	0.03899	F_{11}
F_{23}	0.077627	F_{17}	0.053389	F_4
F_{24}	0.009553	F_8	0.047438	F_8
F_{31}	0.200746	F_{15}	0.062704	F_9
F_{32}	0.014744	F_9	0.039025	F_{17}

F_{33}	0.059922	F_5	0.051427	F_{13}
F_{34}	0.028996	F_{13}	0.046337	F_5
F_{41}	0.038642	F_3	0.06014	F_3
F_{42}	0.018698	F_1	0.044995	F_1
F_{43}	0.113353	F_6	0.084309	F_6

Table 11. The rank of turbines by this study methods and SVNSs TOPSIS and EDAS methods.

Turbines/Rank	SVNSs TOPSIS	SVNSs EDAS	BNSs WSM	BNSs TOPSIS	BNSs VIKOR	BNSs EDAS
T_1	T_2	T_4	T_9	T_2	T_2	T_4
T_2	T_4	T_{10}	T_7	T_4	T_5	T_9
T_3	T_5	T_8	T_{10}	T_5	T_4	T_8
T_4	T_{14}	T_9	T_1	T_3	T_7	T_6
T_5	T_3	T_{11}	T_{15}	T_{14}	T_3	T_{11}
T_6	T_{11}	T_6	T_3	T_7	T_{14}	T_2
T_7	T_7	T_{12}	T_{13}	T_{11}	T_{13}	T_{10}
T_8	T_6	T_1	T_2	T_6	T_{11}	T_1
T_9	T_{13}	T_5	T_8	T_{13}	T_6	T_5
T_{10}	T_{12}	T_2	T_5	T_{12}	T_{12}	T_{14}
T_{11}	T_1	T_{14}	T_{11}	T_{10}	T_{15}	T_7
T_{12}	T_{10}	T_7	T_{12}	T_1	T_1	T_{12}
T_{13}	T_8	T_{15}	T_4	T_{15}	T_8	T_{13}
T_{14}	T_{15}	T_3	T_{14}	T_8	T_{10}	T_{15}
T_{15}	T_9	T_{13}	T_6	T_9	T_9	T_3

5.2 Comparison by Hesitant Fuzzy AHP and TOPSIS[3]

Making a comparison between Hesitant Fuzzy AHP-TOPSIS with this study. First Applying the AHP method to calculate the weights of main and sub criteria. Table 12. Show the comparison weights between AHP and entropy weight method. The results of comparison weight of main criteria show that, the highest weight by AHP method is F_1 and F_2 is the lowest weight. In entropy weight, the F_1 is the highest weight and F_2 is the lowest weight. The weights of sub criteria is computed and ranked in Table 13. In AHP method the F_{20} is the highest weigh in sub criteria and F_{15} is the lowest weight. In entropy weight the F_{22} is the highest weight and F_6 is the lowest weight.

After comparison with the weights of criteria, the turbines is ranked. Comparison by the Hesitant Fuzzy TOPSIS and BNSs WSM, TOPSIS, VIKOR and EDAS. The Rank of turbines is computed in Table 14. In Hesitant Fuzzy TOPSIS show that T_4 is the highest rank and T_9 is the lowest rank.

Table 12. The weights of main criteria by entropy weight and AHP methods.

Criteria/Rank	AHP	Rank by AHP method	Entropy weight	Rank by the entropy weight
F_1	0.355425	F_1	0.423017	F_1
F_2	0.131329	F_3	0.188045	F_3
F_3	0.270759	F_4	0.199494	F_4
F_4	0.242487	F_2	0.189444	F_2

Table 13. The rank weights of sub criteria by AHP and entropy weight methods

Criteria/Rank	AHP	Rank of AHP	Entropy weight	Rank of entropy weight
F_{11}	0.04962	F_{20}	0.021954	F_{22}
F_{12}	0.045957	F_{16}	0.049721	F_{16}
F_{13}	0.035905	F_{19}	0.030774	F_{20}
F_{14}	0.035779	F_{21}	0.042039	F_{14}
F_{15}	0.030804	F_{18}	0.031543	F_7
F_{16}	0.030648	F_{17}	0.020927	F_{18}
F_{17}	0.029155	F_{22}	0.052603	F_2
F_{18}	0.026058	F_1	0.041303	F_{10}
F_{19}	0.024442	F_{12}	0.039383	F_{12}
F_{10}	0.023972	F_2	0.049055	F_{15}
F_{11}	0.023085	F_3	0.043716	F_{19}
F_{21}	0.048331	F_4	0.048228	F_{21}
F_{22}	0.029932	F_{14}	0.03899	F_{11}
F_{23}	0.031933	F_5	0.053389	F_4
F_{24}	0.021132	F_6	0.047438	F_8
F_{31}	0.099028	F_{13}	0.062704	F_9
F_{32}	0.053956	F_7	0.039025	F_{17}
F_{33}	0.056504	F_8	0.051427	F_{13}
F_{34}	0.06127	F_9	0.046337	F_5
F_{41}	0.131909	F_{10}	0.06014	F_3
F_{42}	0.057006	F_{11}	0.044995	F_1
F_{43}	0.053572	F_{15}	0.084309	F_6

Table 14. The rank of turbines by this study methods and Hesitant Fuzzy TOPSIS

Turbines/Rank	Hesitant Fuzzy TOPSIS	BNSs WSM	BNSs TOPSIS	BNSs VIKOR	BNSs EDAS
T_1	T_4	T_9	T_2	T_2	T_4
T_2	T_2	T_7	T_4	T_5	T_9
T_3	T_5	T_{10}	T_5	T_4	T_8
T_4	T_7	T_1	T_3	T_7	T_6
T_5	T_3	T_{15}	T_{14}	T_3	T_{11}
T_6	T_{11}	T_3	T_7	T_{14}	T_2
T_7	T_{14}	T_{13}	T_{11}	T_{13}	T_{10}
T_8	T_{12}	T_2	T_6	T_{11}	T_1
T_9	T_{13}	T_8	T_{13}	T_6	T_5
T_{10}	T_{15}	T_5	T_{12}	T_{12}	T_{14}

T_{11}	T_6	T_{11}	T_{10}	T_{15}	T_7
T_{12}	T_{10}	T_{12}	T_1	T_1	T_{12}
T_{13}	T_1	T_4	T_{15}	T_8	T_{13}
T_{14}	T_8	T_{14}	T_8	T_{10}	T_{15}
T_{15}	T_9	T_6	T_9	T_9	T_3

6. **Sensitivity analysis**

The change criteria weights can affect rank. So needs to change weights of criteria to assess the rank of turbines. In this paper proposed five cases weights changes in Table 15[36]. In case 1 proposed equally weights important for four main criteria. The next cases based on the machine feature, environmental, technological and monetary criteria. The weights of criteria in these cases obtained by divide the weight of criteria by number of criteria (four criteria). Table 16 show the rank of turbines under different cases and methods.

In WSM method, In case 1, the T_9 is the highest turbine rank and T_{14} is the lowest turbine rank. In case 2, T_9 is the highest turbine rank and T_6 is the lowest turbine rank. In case 3, T_9 is the highest turbine rank and T_6 is the lowest turbine rank. In case 4, T_9 is the highest turbine rank and T_{14} is the lowest turbine rank. In case 5, T_{10} is the highest turbine rank and T_{14} is the lowest turbine rank.

In VIKOR method, In case 1, the T_5 is the highest turbine rank and T_9 is the lowest turbine rank. In case 2, T_4 is the highest turbine rank and T_9 is the lowest turbine rank. In case 3, T_6 is the highest turbine rank and T_1 is the lowest turbine rank. In case 4, T_{13} is the highest turbine rank and T_{12} is the lowest turbine rank. In case 5, T_4 is the highest turbine rank and T_5 is the lowest turbine rank.

In TOPSIS method, In case 1, the T_5 is the highest turbine rank and T_9 is the lowest turbine rank. In case 2, T_2 is the highest turbine rank and T_9 is the lowest turbine rank. In case 3, T_5 is the highest turbine rank and T_1 is the lowest turbine rank. In case 4, T_{13} is the highest turbine rank and T_{12} is the lowest turbine rank. In case 5, T_4 is the highest turbine rank and T_9 is the lowest turbine rank.

In EDAS method, In case 1, the T_4 is the highest turbine rank and T_{15} is the lowest turbine rank. In case 2, T_4 is the highest turbine rank and T_3 is the lowest turbine rank. In case 3, T_6 is the highest turbine rank and T_{15} is the lowest turbine rank. In case 4, T_4 is the highest turbine rank and T_3 is the lowest turbine rank. In case 5, T_4 is the highest turbine rank and T_{12} is the lowest turbine rank.

Due to the MCDM methods have different rank results. So, proposed the combination method to aggregate the turbines rank. If there are h alternative, the highest rank takes h points and second rank takes h-1 points, third rank takes h-2 points and so on. The turbines is the highest points takes the best turbines[36]. Table 17 show the combination rank.

Table 15. The five case of change weight.

Turbines/Rank	Machine Feature	Environmental/Habitat	Technological	Monetary
Case 1 Equal important	0.25	0.25	0.25	0.25
Case 2 Machine Feature	0.5	0.1667	0.1667	0.1667
Case 3 Environmental/Habitat	0.1667	0.5	0.1667	0.1667
Case 4 Technological	0.1667	0.1667	0.5	0.1667
Case 5 Monetary	0.1667	0.1667	0.1667	0.5

Table 16. The rank of turbines by five cases of weights.

WSM					VIKOR					TOPSIS					EDAS				
Case 1	Case 2	Case 3	Case 4	Case 5	Case 1	Case 2	Case 3	Case 4	Case 5	Case 1	Case 2	Case 3	Case 4	Case 5	Case 1	Case 2	Case 3	Case 4	Case 5
T_9	T_9	T_9	T_9	T_{10}	T5	T4	T6	T13	T4	T5	T2	T5	T13	T4	T4	T4	T6	T4	T4
T_{10}	T_7	T_{15}	T_{10}	T_9	T2	T2	T5	T3	T5	T2	T4	T6	T3	T5	T9	T9	T4	T6	T9
T_{15}	T_{10}	T_7	T_1	T_{15}	T4	T5	T4	T6	T3	T4	T5	T4	T6	T3	T6	T8	T9	T8	T8
T_7	T_1	T_{10}	T_{15}	T_1	T3	T3	T2	T7	T14	T3	T3	T7	T7	T14	T8	T6	T1	T9	T6
T_1	T_{15}	T_3	T_3	T_7	T7	T13	T11	T8	T2	T14	T14	T2	T1	T2	T5	T10	T8	T5	T14
T_3	T_3	T_1	T_7	T_{11}	T14	T7	T14	T9	T12	T11	T7	T11	T10	T11	T1	T11	T7	T11	T5
T_{13}	T_2	T_5	T_{13}	T_3	T11	T12	T7	T1	T11	T7	T13	T8	T2	T12	T11	T2	T5	T1	T2
T_5	T_{13}	T_{13}	T_5	T_8	T13	T14	T8	T5	T7	T6	T11	T14	T9	T7	T2	T1	T11	T14	T11
T_8	T_8	T_8	T_{11}	T_{13}	T6	T6	T15	T2	T13	T13	T12	T10	T15	T10	T14	T5	T12	T12	T10
T_{11}	T_5	T_{11}	T_8	T_2	T12	T11	T10	T15	T6	T12	T6	T9	T8	T13	T10	T7	T2	T2	T1
T_2	T_{11}	T_4	T_2	T_5	T15	T1	T12	T10	T10	T10	T1	T12	T14	T6	T7	T14	T13	T10	T3
T_{12}	T_{12}	T_{12}	T_{12}	T_{12}	T10	T15	T3	T14	T15	T15	T10	T15	T5	T15	T13	T12	T14	T13	T13
T_4	T_4	T_2	T_4	T_6	T1	T8	T13	T4	T1	T1	T8	T13	T4	T1	T12	T13	T10	T7	T15

T_6	T_{14}	T_{14}	T_6	T_4	T8	T10	T9	T11	T8	T8	T15	T3	T11	T8	T3	T15	T3	T15	T7
T_{14}	T_6	T_6	T_{14}	T_{14}	T9	T9	T1	T12	T9	T9	T9	T1	T12	T9	T15	T3	T15	T3	T12

Table 17. The combination rank for five case weights.

WSM	VIKOR	TOPSIS	EDAS
T_9	T_5	T_5	T_4
T_{10}	T_4	T_2	T_9
T_{15}	T_2	T_4	T_6
T_7	T_3	T_3	T_8
T_1	T_7	T_7	T_5
T_3	T_6	T_{14}	T_1
T_{13}	T_{13}	T_6	T_{11}
T_5	T_{14}	T_{11}	T_2
T_8	T_{11}	T_{13}	T_{14}
T_{11}	T_{12}	T_{10}	T_{10}
T_2	T_8	T_{12}	T_7
T_{12}	T_{15}	T_1	T_{12}
T_4	T_{10}	T_8	T_{13}
T_6	T_1	T_{15}	T_3
T_{14}	T_9	T_9	T_{15}

7. Conclusions

Many countries go toward using the renewable energy instead of using fossil fuel in recent years. The wind energy is a source of renewable energy. So, increasing the importance of selection the best wind turbine. In this paper discuss the selection best wind turbine for Egypt to build a new farm in the government red sea. First the criteria is collected from the literature review. The opinions of experts and decision makers are collected. The twenty two sub criteria and four main criteria is collected. The fifteen turbines were determined. The weights of criteria is computed by the entropy weight method. The turbines were ranked by the WSM, VIKOR, TOPSIS and EDAS methods with bipolar neutrosophic sets. Base on the results show that the T_2 is the highest rank and T_{12} is the lowest rank.

The future work can apply another MCDM methods for this problem.

Conflict of interest

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

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Ethical approval

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

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