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A Multi Criteria Decision Making Approach for the Selection of Optimum Location for Wind Power Project in India

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Abstract

This study tried to find out the selection of site for the wind turbine in India. We have chosen six wind power projects which are located different places in India. Wind power, Hub height, Distance, Cost, CO_2, Wind speed and Blade height are the seven criteria had taken for the selection of best location. The analytical hierarchy process (AHP) is integrated with technique for order reference by similarity to ideal solution (TOPSIS) to meet the objective of this study. Firstly, the weights of each criterion are to determine using AHP. These weights will be used in TOPSIS method to select the best project. A case study is performed to exhibit the application of the methods was conducted to evaluate six types of wind power projects. The AHP-TOPSIS result showed that the Muppandal wind farm, Kanyakumari is the best wind power project among the six projects.

Keywords: AHP, Energy, MCDM, Renewable Source, TOPSIS, Wind turbine selection

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1. Introduction

These days, ozone consumption, expanding worldwide normal temperature, environmental change, various kinds of contamination, and high reliance on petroleum products are some the significant issues confronting humankind. Clearly wellsprings of coal, oil, and gas will in the end evaporate within a reasonable time-frame. In this way, the expanded utilization of perfect and sustainable power sources is one of the measures that many created nations have taken in ongoing decades to handle these issues somewhat. The advancement of sustainable power source innovation and its going with benefits, for example, decreased contamination, plenitude, and changelessness have caused this sort of vitality, particularly wind vitality, to turn out to be financially reasonable and to be seen well by all specialists regarding this matter.

Wind, as other sustainable power sources, is geologically across the board and is quite often accessible; nonetheless, it is additionally scattered and decentralized and has a fluctuating and irregular nature. The Analytic Hierarchy Process (AHP), presented by Thomas Saaty (1980), is a compelling apparatus for complex decision making, and may help the chief to set needs and settle on the best choice. By decreasing complex choices to a progression of pairwise examinations, and afterward blending the outcomes, the AHP assists with catching both emotional and target parts of a choice. Likewise, the AHP consolidates a helpful strategy for checking the consistency of the chief's assessments, in this way lessening the predisposition in the dynamic procedure.

The paper is organized as follows: after the introduction and literature survey, Section 3 presents the methodology with mathematical formulation of the new MCDM method and the basic steps of the AHP and TOPSIS. The Section 4 presents results with an application of the AHP and TOPSIS calculations. The final section (Section 5) presents the conclusion. The aim of this paper is to choose the best project Windmill in India. Here six Windmills have been chosen as projects and seven criteria's for selection.

2. Literature Review

Sustainable power source is developing as an answer for a sustainable, environmentally well-disposed and long haul, savvy wellspring of vitality for what's to come. Sustainable power source choices are equipped for supplanting ordinary wellsprings of vitality in a large portion of their applications at serious long haul costs [1,2]. In spite of the fact that AHP is anything but difficult to utilize and apply, its unidirectional relationship trademark can't deal with the multifaceted nature of numerous issues. ANP, in any case, manages the issue as a system of complex connections among options and criteria where all the components can be associated. Cheng and Li an experimental guide to delineate utilization of ANP [3]. Begic and Afgan evaluated the options of energy power systems for Bosnia Herzegovina under a multi-criteria sustainability assessment framework in order to investigate options for the selection of new capacity building of this complex system [4].

Ivanova et al. surveyed the attainability of wind power plant development in an electric force framework utilizing a progressive multi-criteria approach [5]. Charnes, A et al., (1978) proposed a nonlinear (nonconvex) programming model which gives another meaning of effectiveness for use in assessing exercises of not-revenue driven substances taking an interest openly programs. Haworth, N et al., (2012) discussed about PTWs and will keep on developing as they assume a significant job in both vehicle and entertainment over the world. Their examples of utilization contrast notably between and among created and creating nations and this influences the wellbeing difficulties and portability openings that they speak to.Pamučar, D et al., (2015) indicated that the TOPSIS, MOORA, SAW, COPRAS and VIKOR techniques don't meet at least one conditions set, but the MABAC strategy demonstrated soundness in its answers. Through the exploration introduced right now, is indicated that the new MABAC technique for MCDM is a helpful and solid apparatus for rational decision-making.

Amer et.al., (2011) Utilized MCDM just because for the vitality area of Pakistan. Introduced AHP model for the choice and prioritization of different sustainable power source advances for power age. Wind vitality, sun based photovoltaic, sun oriented warm, and biomass vitality were utilized as choices. Martin et al. (2013) introduced a technique to assess various drifting help structure designs, for seaward wind turbines sent in profound waters. Datta et al. (2014) recognized the best islanding recognition strategy for a sunlight based photovoltaic framework by utilizing TOPSIS alongside other MCDM strategies. Kahraman et.al., (2010) executed a fuzzy MCDMmethod, in view of the AHP strategy, to locate the ideal among vitality strategies in Turkey.

3. Methodology

Proposed Methodology for Optimum Solution:

In order to find out the best wind power project out of 6 projects firstly we need to estimate the criteria weights using Analytical Hierarchy Process (AHP). Using these criteria weights, next we have to find out the rankings for all the projects using MCDM technique like TOPSIS [4]. Finally, we will rank the projects based on their performance score.

Seven criteria's which we had taken for selecting the best wind power project are given below:

Wind power: The amount of power generated is very important for any power project, the generated power should be more which is measured in Mega Watts (MW).

Hub height: The hub height is also another important criteria and had taken more the hub height higher is the power generated which is measured in Meters (m).

Distance: The distance from power plant to the grid should be less and it is measured in Meters (m).

Cost: For installing any power plant we should have sufficient funds or we have should invest money on it. So, the cost of plant is also plays an important role in establishment of a power plant which is measured in Crores.

CO_2: By choosing renewable energy sources we can reduce the amount of CO_2 emissions (million tonnes reduced) over Conventional sources.

Wind speed: The speed of the wind for the particular plant location should be more in order to generate more power and it is measured in meter/second.

Blade height: For any wind power project the blade height will also plays a key role in generation of power. Based on the rotation of the blade the turbine will rotate which in turn rotates the rotor of the generator. Here I have taken less blade is the best one which is measured in Meters (m).

3.1 Analytical Hierarchy Process (AHP)

This method is used to calculate the weights of the criteria. It mainly involves 3 steps.

Step 1:
Firstly we have to develop a hierarchal structure shown in the below figure with the goal at the top level, the criteria at the second level and the projects at third level.
In this I am considering 6 Projects i.e., windmills and 7 Criteria's.

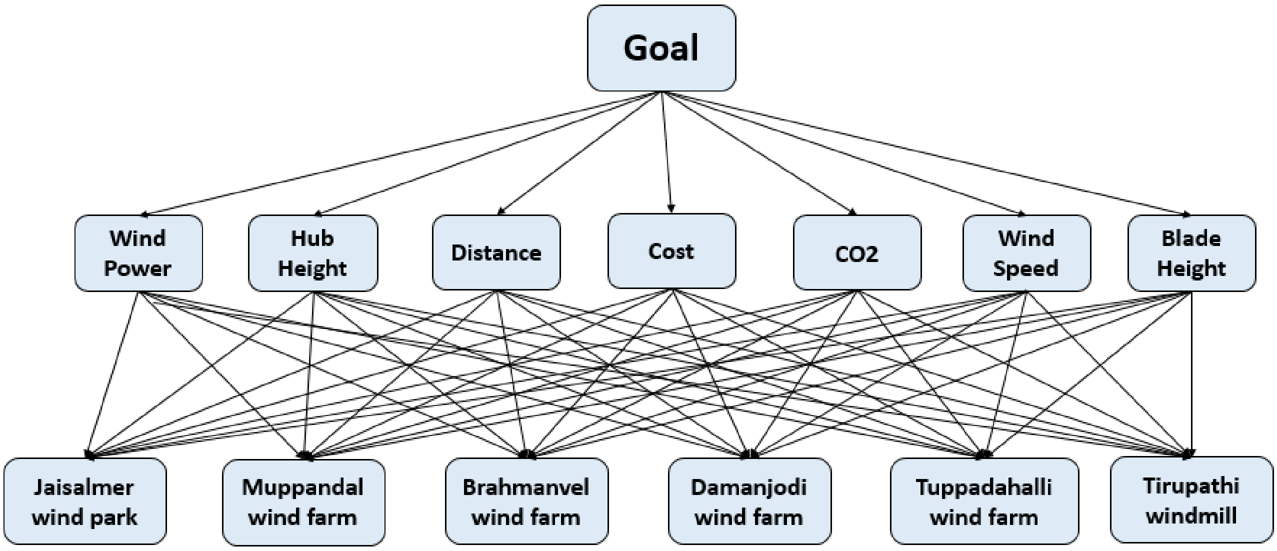

Figure 1. Decision Hierarchy

Step 2:
This step involves developing of pair wise comparison matrix.
Which is haing a matrix size of 7*7 shown in Table 2.
After that normalized pair wise comparison matrix has to be created which is shown in Table 3.
Step 3:
Calculating the consistency matrix which is shown in Table 4.
Then weighted sum value is calculated by adding all the values in the particular row. After that ratio of weighted sum value to the criteria weight has to be calculated for each row.

Now, lambda max is calculated by taking the average of these values. Then consistency index is to be calculated.
λ = Weighted Sum Value / Criteria Weight (1)
Using equation (1) the resulting value shown in Table 5

Consistency index (C.I) = (λmax-n)/(n-1) (2)
Consistency Ratio = C.I/ R.C.I (3)
The consistency ratio is then calculated and the value of consistency ratio should be less than 0.1. Then the obtained criteria weights are correct.

3.2 TOPSIS Method

Now, we were dealing the selection of best wind power project out of 6 projects. Criteria's are Wind power, Hub height, Distance, Cost, CO_2, Wind speed and Blade height.

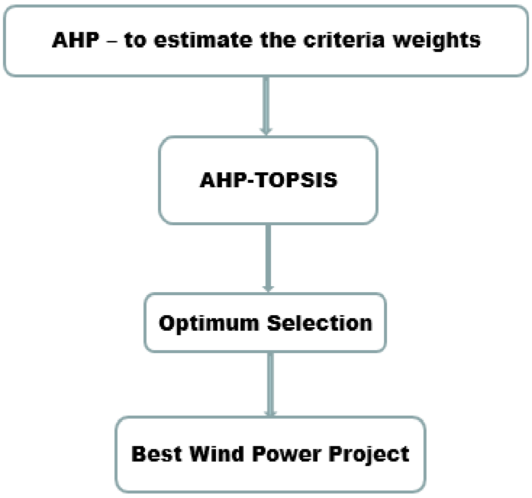

Figure 2. Step by Step procedure for selection of wind power project

The procedure of TOPSIS method is as follows:

Step 1: Construction of decision matrix:

It is the matrix formed between Projects and Criteria's and the size of the matrix is 6*7.
Criteria's as X-axis and Projects as Y-axis. The decision matrix which is shown in Table 8

Step 2: Normalization of the evaluation matrix:

The determination of normalized values of projects X_{ij}:

$$\overline{X_{ij}} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n}(x_{ij})^2}}, \; i = 1,2,\ldots,m; \; j = 1,2,\ldots,n. \quad (4)$$

Using equation (4) normalized decision matrix is shown in Table 9.
Step 3: Construction of the weighted normalized decision matrix:

It can be calculated by multiplying the normalized evaluation matrix X_{ij} with its associated weight w_j (shown in Table 8) to obtain the result.

$$V_{ij} = \bar{X}_{ij} \times W_j \quad (5)$$

Using equation (5) weighted normalized decision matrix is shown in Table 10.

Step 4: Determination of the positive and negative ideal solutions:

V_i^+ is maximum value as a best project for beneficial.
V_i^- is minimum value as a worst project for beneficial.
V_i^+ & V_i^- is shown in Table 11.

Step 5: Calculation of the Euclidean distance:

$$S_i^+ = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^+)^2} \quad (6)$$

$$S_i^- = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^-)^2} \quad (7)$$

Using equations (6) & (7), S_i^+ & S_i^- is shown in Table 12.

Step 6: Calculating Performance score:

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (8)$$

Using equation (8) P_i is shown in Table 13.

Step 7: Ranking the priority:

The ranking is made according to the descending order of Pi.
The project with more score will be ranked first.

4. Results and Discussion

4.1 AHP Calculations

The choice chain of importance chart is set up utilizing recognized assessment criteria and the elective mixes. The choice model comprises of three levels, specifically, the target of the issue, criteria and the other options, which are situated at the significant level, second level and the base level individually. After the development of the progressive system graph for the issue as referenced, the AHP strategy requires the pair-wise examination of the criteria so as to decide their relative loads. In the pair shrewd examination process, every paradigm is contrasted and others utilizing saaty's nine point scale [3].

Table 1. Nomenclature

Criteria's	**Wind Power Project**
CT1 - Wind power (MW) CT2 - Hub height (m) CT3 – Distance (m) CT4 – Cost (crores) CT5 – CO_2 (million tonnes reduced) CT6 - Wind speed (m/s) CT7 - Blade height (m)	WPP1 – Jaisalmer wind park, Rajasthan WPP2 – Muppandal wind farm, Kanyakumari WPP3 – Brahmanvel wind farm, Maharashtra WPP4 – Damanjodi wind farm, Odisha WPP5 – Tuppadahalli wind farm, Karnataka WPP6 – Tirupathi windmill, Tirupathi

Firstly, we have to calculated the pair wise comparison matrix using seven criteria's which is of 7*7 size. This matrix was completely depending upon scale of importance given from 1 to 9. It will be variable for person to person.

Table 2. Comparison of pair-wise matrix

Criteria's	CT1	CT2	CT3	CT4	CT5	CT6	CT7
CT1	1	0.5	0.5	0.333	0.333	0.5	0.25
CT2	2	1	0.25	0.333	0.5	0.333	0.333
CT3	2	4	1	0.25	0.333	0.333	0.25
CT4	3	3	5	1	2	0.5	0.333
CT5	3	2	3	0.5	1	0.5	0.333
CT6	2	3	3	2	2	1	0.5
CT7	4	3	4	3	2	2	1

Table 3. Normalised Pair-wise matrix

Criteria's	CT1	CT2	CT3	CT4	CT5	CT6	CT7
CT1	0.0588	0.0303	0.0299	0.0449	0.0408	0.0968	0.0834
CT2	0.1176	0.0606	0.0149	0.0449	0.0612	0.0645	0.1110
CT3	0.1176	0.2424	0.0597	0.0337	0.0408	0.0645	0.0834
CT4	0.1765	0.1818	0.2985	0.1348	0.2449	0.0968	0.1110
CT5	0.1765	0.1212	0.1791	0.0674	0.1225	0.0968	0.1110
CT6	0.1176	0.1818	0.1791	0.2697	0.2449	0.1936	0.1667
CT7	0.2353	0.1818	0.2388	0.4045	0.2449	0.3871	0.3334

Table 4. Calculating the Consistency

Criteria's	CT1	CT2	CT3	CT4	CT5	CT6	CT7
CT1	0.0550	0.0339	0.0459	0.0592	0.0416	0.0967	0.0724
CT2	0.1099	0.0678	0.0229	0.0592	0.0625	0.0644	0.0964
CT3	0.1099	0.2713	0.0917	0.0444	0.0416	0.0644	0.0724
CT4	0.1649	0.2035	0.4586	0.1778	0.2499	0.0967	0.0964
CT5	0.1649	0.1357	0.2752	0.0889	0.1249	0.0967	0.0964
CT6	0.1099	0.2035	0.2752	0.3555	0.2499	0.1934	0.1447
CT7	0.2199	0.2035	0.3669	0.5333	0.2499	0.3867	0.2894

Table 5. Calculation of λ

Criteria	Weighted Sum Value	Criteria Weights	λ
CT1	0.40458	0.054972	7.359697
CT2	0.483131	0.06783	7.122707
CT3	0.695775	0.091726	7.585344
CT4	1.447715	0.177769	8.14381
CT5	0.982621	0.124927	7.86554
CT6	1.532069	0.193353	7.923693
CT7	2.249573	0.289423	7.772624

λmax = Average Value of λ = 7.681916
From equation (2),
Consistency index (C.I) =0.113653
n – number of criteria = 7

Table 6. Random Index

No	1	2	3	4	5	6	7	8	9	10
RCI	0.00	0.00	0.58	0.90	1.12	1.24	**1.32**	1.41	1.45	1.49

From equation (3),
Consistency Ratio = 0.086101< **0.10**

Since we got 0.086101 i.e., 8.61% error only which is less than 10% then we have considered the criteria weights which we got from Analytical Hierarchy Process. If the error is more than 10%, then we should repeat the entire AHP steps until we got the error less than 10%.

Once the criteria weights are finalised, it will be used in TOPSIS method for ranking the wind power projects.

4.2 TOPSIS Calculations

Table 7. Beneficial and Non-beneficial criterion values calculated using AHP

Criteria	CT1	CT2	CT3	CT4	CT5	CT6	CT7
Beneficial / Non-beneficial	Benficial	Benficial	Non Benficial	Non Benficial	Benficial	Benficial	Non Benficial
Weight (W_j)	**0.05497**	**0.06782**	**0.09172**	**0.17776**	**0.12492**	**0.19335**	**0.28942**

The above table consists of weights of each criteria which we got from AHP method.

The complete data for each wind power project is given below will be used for ranking the projects using TOPSIS algorithm.

Table 8. Decision Matrix for projects

Project's	CT1	CT2	CT3	CT4	CT5	CT6	CT7
WPP1	1064	120	1700	14500	0.21	15.3	70
WPP2	1500	120	1900	10500	4.2	19	60
WPP3	650	120	2000	8000	1.75	5	80
WPP4	150	120	1500	6000	1	2	50
WPP5	56.1	120	2500	4000	1.29	5	70
WPP6	6	78	2600	2000	0.9	11	30

Table 9. Normalized matrix

Project's	CT1	CT2	CT3	CT4	CT5	CT6	CT7
WPP1	0.5437	0.4294	0.3349	0.6909	0.0427	0.5513	0.4596
WPP2	0.7664	0.4294	0.3744	0.5003	0.8534	0.6847	0.3939
WPP3	0.3321	0.4294	0.3941	0.3812	0.3556	0.1802	0.5252
WPP4	0.0766	0.4294	0.2955	0.2859	0.2032	0.0721	0.3283
WPP5	0.0287	0.4294	0.4926	0.1906	0.2621	0.1802	0.4596
WPP6	0.0031	0.2791	0.5123	0.0953	0.1829	0.3964	0.1970

Table 10. Weighted Normalized matrix

Project's	CT1	CT2	CT3	CT4	CT5	CT6	CT7
WPP1	0.0299	0.0291	0.0307	0.1228	0.0053	0.1066	0.1330
WPP2	0.0421	0.0291	0.0343	0.0889	0.1066	0.1324	0.1140
WPP3	0.0183	0.0291	0.0361	0.0678	0.0444	0.0348	0.1520
WPP4	0.0042	0.0291	0.0271	0.0508	0.0254	0.0139	0.0950
WPP5	0.0016	0.0291	0.0452	0.0339	0.0327	0.0348	0.1330
WPP6	0.0002	0.0189	0.0470	0.0169	0.0228	0.0766	0.0570

Table 11. Best value V_i^* and worst value V_i^-

Criteria	CT1	CT2	CT3	CT4	CT5	CT6	CT7
V_i^*	0.04213	0.02913	0.02711	0.01694	0.10661	0.13238	0.05700
V_i^-	0.00017	0.01893	0.04699	0.12281	0.00533	0.01394	0.15201

Table 12. Euclidean distance from ideal best Si^+ and from ideal worst Si^-

Project's	WPP1	WPP2	WPP3	WPP4	WPP5	WPP6
Si*	0.167548	0.092114	0.160137	0.157029	0.151681	0.111284
Si-	0.100996	0.170016	0.074464	0.096698	0.097817	0.156445

Table 13. Performance Score using TOPSIS with AHP

Project's	WPP1	WPP2	WPP3	WPP4	WPP5	WPP6
P_i	0.376087	***0.648593***	0.317407	0.381109	0.392055	0.58434
Rank	5	***1***	6	4	3	2

Finally, from the above table, Muppandal wind farm, Kanyakumari (WPP2) ranked the best project among six windfarms and the order of preference is as follows:

WPP2(0.648593)>WPP6(0.58434)>WPP5(0.392055)>WPP4(0.381109)>WPP1(0.376087)>WPP3 (0.317407)**.** Here WPP2 is having a score of 0.648593 which is close to ideal solution i.e.1.

Here Analytical Hierarchy Process method is used to find the criteria weights, those will be used in TOPSIS algorithm to rank the projects from performance scores of all projects.
The proposed methodology for the selection of best windfarm [1,5] among six projects which are located in different places of India has done using MCDM method. After finding the performance score using different criteria's, it is observed that the Muppandal wind farm, Kanyakumari and Tirupathi windmill, Tirupathi obtained the relative closeness to ideal solution and the values are 0.5462 and 0.58434 respectively. From the results it is observed Muppandal wind farm, Kanyakumari is identified as the best wind power project among the considered ones which has the best relative closeness value since it is having high generating capacity of 1500MW, high wind speed of 19m/s and it is saving the environment from CO_2 (4.2 million tonnes reduced).

Since TOPSIS is one of the multi criteria decision making approach, one of the best method for selecting a best site location for wind power projects, solar power project and many other purposes. I have chosen this method because it gives the best closest value to the ideal solution i.e., 1. All the steps in this method is understandable and easy to execute. So whenever any organisation or company wanted to install a wind power project, firstly they have to identify the best location for that. Not only installed power capacity, so many other factors are also they have to consider, like wind speed, amount of CO2 emissions can be reduced, tower height, blade length etc., For those organisations or companies this method is a reference for them to start a project to give best results.

5. Conclusion

It is observed that Muppandal wind farm, Kanyakumari (WPP2) ranked the best project among six windfarms with a score of 0.648593 which is having relative closeness to the ideal solution based on several criteria's. Since the TOPSIS is having more steps and calculations, the performance score is not exactly nearer to ideal solution i.e., the first ranked Muppandal wind farm, Kanyakumari having a score of 0.648593 is not relatively closeness to ideal solution 1. In order to overcome this problem, in future AHP can be integrated with VIKOR method which is having best relative closeness to ideal solution.

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