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A SITE SELECTION STUDY OF WIND POWER PLANTS BASED ON FUZZY-TOPSIS METHOD

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Abstract

Selecting a renewable and green energy in power plant is inevitable; however, in an attempt to find the best site, there are a variety of criteria to select. This study aims to find the most effective and recommended Wind Power Plant (WPP) site in Indonesia utilizing an artificial intelligence (AI) – based multi-criteria decision making (MCDM) namely Fuzzy-TOPSIS Method. In terms of research procedure employing the combination of analytical hierarchy process (AHP) and fuzzy-TOPSIS method, this study started with determination of sub-criteria to be used from relevant literature to assessment of criteria consistency through pairwise comparison. The results showed that through a combination of both AHP and fuzzy-TOPSIS methods, there are 10 important criteria to be considered for selecting the most effective WPP site. It is also implied that the sequentially ordered criteria based on priorities have revealed at least two sites of the WPP.

Keywords: Artificial intelligence (AI) – based, Fuzzy-TOPSIS method,. Multi-criteria decision making (MCDM), Wind power plants (WPP).

1. Introduction

The increasing demand for energy around the world has forced planners and policy makers to consider the development of non-conventional energy sources, the utilization of renewable energy is considered as one of the most promising solutions to overcome this challenge [1]. Wind power is one of the fastest growing renewable energy technologies and offers a reliable, cost-effective and environmentally friendly way to generate electrical energy [2, 3]. Of the various renewable energy sources used for power generation, wind energy is one of the most promising renewable energies [1, 4].

Evaluation and site selection in wind generation establishments is a complex multi-criteria problem because it takes into account different evaluation criteria [5], requires careful analysis and requires resolving conflicting factors of economic and technological nature, with ecological and social limitations, also respecting opinions public [3].

The multi-criteria decision-making method (MCDM) is effective in overcoming complex and conflicting multi-criteria problems [6, 7]. The application of the MCDM method has been carried out in many disciplines, Gwo-Hsiung et al. [8], studied the use of MCDM for the development of new energy systems in Taiwan based on AHP and Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE).

Choudhary and Shankar [9] proposed a model for evaluating the most appropriate location for Thermal Power Plant using AHP and TOPSIS methods. Chatterjee and Bose [10] evaluated locations for wind farms using the COPRAS (Complex Proportional Assessment) based MCDM methodology under a fuzzy environment. Atici et al. [11] proposed a selection model for Wind Power Plant based on Geographic Information Systems (GIS) and the ELECTRE method.

Latinopoulos and Kechagia [12] proposed a model for evaluating GIS-based wind farm location and multi-criteria spatial decision analysis. Ali et al. [13] used GIS and fuzzy AHP methods to achieve optimal site selection decisions. Of the many uses of the multi-criteria decision-making approach by experts, the AHP and Fuzzy-TOPSIS methods are popular methodologies that are widely used in solving MCDM problems [14] and one of the best methods in determining the selection of the best location for Wind Power Plant [15].

The AHP method is the only methodology that can consider the consistency of decision makers and the main advantage of this method is that it is relatively easy to handle many criteria and can be applied to both qualitative and quantitative data [14, 16]. And the Fuzzy-TOPSIS method to quickly determine the best alternative ranking, where this method works based on the principle of compromise and has the ability to handle conflicting situations [14, 17, 18].

This study proposes an alternative location for Wind Power Plant with the development of multi-criteria decision making based on artificial intelligence by focusing on determining the priority order of sub-criteria considered in the selection of Wind Power Plant locations using the AHP method and determining the feasibility of Wind Power Plant locations using the Fuzzy-TOPSIS method.

2. Methods

2.1. Research procedure

In this study, the first step is a literature study looking for data, related information, and collecting various expert opinions published in reputable national and international journals sourced from the Google Scholar, IEEE, ScienceDirect, and Research Gate databases. Based on the literature study conducted, the supporting criteria for the location of Wind Power Plant were obtained, and an assessment of the weight of the criteria was obtained. Then using the AHP method, the priority order of the criteria is determined. Calculations on the AHP method are done manually using Microsoft Excel and Expert Choice software. Calculation results can be accepted and considered consistent if the value of consistency ratio (CR) < 0.1 or < 10%. If the CR value is > 0.1 or > 10% then the calculation needs to be re-examined. Furthermore, the calculation of the Fuzzy-TOPSIS method is carried out using the priority vector value on the AHP method as the weight of the assessment on the Fuzzy-TOPSIS method in determining the feasibility of the location of the Wind Power Plant establishment.

The research focuses on the study area located in East Sumba Regency, Indonesia, precisely in Pamburu Village in Pahunga Lodu District and Kadahang Village in Haharu District. By using the Analytical Hierarchy Process (AHP) algorithm, data processing is carried out through manual calculations in Microsoft Excel and Expert Choice software and using the Fuzzy-TOPSIS (Technique for Others Reference by Similarity to Ideal Solution) algorithm in determining the location of Wind Power Plant.

The AHP method is an MCDM approach that can handle many criteria and can be applied to both qualitative and quantitative data using a pairwise comparison matrix [14, 16, 19] as shown in Table 1.

Table 1. Basic pairwise comparison scale [20-22].

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two criteria contribute equally to the goal or have the same influence
3	Moderate Importance	One criterion is slightly more important than the other. Judgment and experience slightly support one criterion over another
5	Strong Importance	One criterion is more important than the other criteria. Judgment and experience strongly support one criterion compared to another
7	Very Strong Importance	One criterion is more important than the other criteria. One criterion is very strong in support of the other criteria
9	Extreme Importance	One criterion is absolutely important than the other criteria. Evidence that supports one criterion against another has the highest possible validity
2,4,6,8	Intermediate Values	The value given when there are two compromises between the criteria
Reciprocals	Value for reverse comparison	If criterion i has one of the above numbers assigned to it when compared to criterion j, then j has a reciprocal value when compared to i

There are four steps involved in the process comprising (1) determining some important sub-criteria to be used from the literature study conducted; (2) determining the Pairwise Comparison Matrices. Determined by assessing the relative importance of each criterion to one another. This is done using a scale from 1 to 9; (3) normalizing Pairwise Comparison Matrices; and (4) Assessment of consistency through pairwise comparisons. There is also a process namely consistency ratio (CR) which involves calculating the priority vector for a criterion; computing max (Main Eigenvalues); calculating Consistency Index (CI); determining the appropriate random value Consistency Ratio (RI); and calculating Consistency Ratio (CR) [20]. Table 2 provides a summary for the random mean Consistency Ratio (RI) using N number of criteria (N = 1 to N = 15).

Table 2. Random consistency index (RI) [20].

Number of criteria (N)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
RI	0	0.0	0.58	0.90	1.12	1.24	1.32	1.41
Number of criteria (N)	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
RI	1.45	1.49	1.51	1.54	1.56	1.57	1.59	

3. Results and Discussion

3.1. Criteria for supporting Wind Power Plant location

This study aims to determine the important criteria in determining the feasibility of establishing a Wind Power Plant. Literature study was conducted to collect various expert opinions published in reputable national and international journals. Based on search results from the Google Scholar, IEEE, ScienceDirect, and Research Gate databases, 30 scientific journals were collected that were used as references to collect various opinions on technical, geographical, socio-economic and environmental criteria in determining the location of Wind Power Plants. Table 3 shows the results of the synthesis of the literature that has collected 18 criteria for consideration in establishing Wind Power Plant. As a consideration for determining multi-criteria decisions, researchers only chose the top ten criteria, because these criteria were considered by most global researchers.

The top ten criteria are used as sub-criteria and classified according to their field which is used as the main criteria. This is illustrated in Fig. 1. The top ten criteria will be prioritized using the AHP method.

Table 3. Results of literature synthesis determination of main criteria considerations for determining the location of Wind Power Plant.

No.	Sub-Criteria	References	No	Sub-Criteria	References
1	Wind Speed (WS)	[2, 3, 5, 15, 20-25]	10	Cost (CS)	[23, 15, 27]
2	Slope (SP)	[3, 11, 20-22, 25]	11	Capacity Factor	[11, 23]
3	Distance to Roads (DR)	[11, 24, 25]	12	Distance to Transmission Lines	[11, 24]
4	Land Use (LU)	[3, 20, 21, 24]	13	Distance to Residential Area	[24, 25]
5	Elevation (EL)	[11, 20, 21, 22, 25]	14	Wind Potential	[27]
6	Wind Density (WD)	[5, 23]	15	Distance to Protected Areas	[6]
7	Distance to Networks (DN)	[5, 11, 23, 26].	16	Land Availability	[26]
8	Distance to Urban Places (UP)	[3, 11]	17	Population Density	[23]
9	Distance to Airports (DA)	[11, 24]	18	Soil Condition	[25]

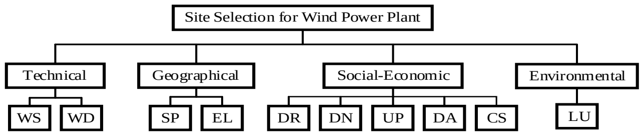

Fig. 1. Hierarchical structure of Wind Power Plant site selection.

Calculation results of Analytical Hierarchy Process (AHP)

Forming Pairwise Comparison Matrices in the AHP scale is considered the first step. From each comparison of each sub-criteria, the weight of the assessment is given based on the importance of the sub-criteria that is taken into consideration for the establishment of Wind Power Plant and the number of journals that list the level of importance of one sub-criteria with other sub-criteria. The order of priority is obtained from the results of the normalization of the Pairwise Comparison matrix. Table 4 shows the calculation results in determining the order of priority of the sub-criteria and Table 5 presents the order of sub-criteria which have been enlisted in terms of priorities.

Table 4. Pairwise comparison AHP scale.

Sub-criteria	WS	WD	DN	EL	SP	DA	LU	UP	DR	CS	SUM
WS	1	3	5	3	3	5	5	7	7	7	3.0286
WD	1/3	1	3	3	3	5	3	5	3	7	6.2095
DN	1/5	1/3	1	1/3	1/3	3	2	2	2	3	17.167
EL	1/3	1/3	3	1	1/3	3	3	3	3	3	12
SP	1/3	1/3	3	3	1	2	1/3	3	3	3	12.167
DA	1/5	1/5	1/3	1/3	1/2	1	1/3	3	1/2	3	24.667
LU	1/5	1/3	0.5	1/3	3	3	1	2	2	3	16
UP	1/7	1/5	0.5	1/3	1/3	1/3	1/2	1	1/2	3	28.333
DR	1/7	1/3	0.5	1/3	1/3	2	1/2	2	1	3	22.333
CS	1/7	1/7	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1	36

Pairwise Comparison Matrices Normalized

Sub-criteria	WS	WD	DN	EL	SP	DA	LU	UP	DR	CS	SUM	Priority Vectors
WS	0.3301	0.4831	0.2913	0.25	0.2466	0.2027	0.3125	0.2471	0.3134	0.1944	2.8712	0.2871
WD	0.1100	0.161	0.1748	0.25	0.2466	0.2027	0.1875	0.1765	0.1343	0.1944	1.8378	0.1837
DN	0.0660	0.0537	0.0583	0.0278	0.0274	0.1216	0.125	0.0706	0.0895	0.0833	0.7232	0.0723
EL	0.1100	0.0537	0.1748	0.0833	0.0274	0.1216	0.1875	0.1059	0.1343	0.0833	1.0818	0.1081
SP	0.1100	0.0537	0.1748	0.25	0.0822	0.0811	0.0208	0.1059	0.1343	0.0833	1.0961	0.1096
DA	0.0660	0.0322	0.0194	0.0278	0.0411	0.0405	0.0208	0.1059	0.0223	0.0833	0.4595	0.0459
LU	0.0660	0.0537	0.0291	0.0278	0.2466	0.1216	0.0625	0.0706	0.0895	0.0833	0.8507	0.0850
UP	0.0471	0.0322	0.0291	0.0278	0.0274	0.0135	0.0312	0.0353	0.0223	0.0833	0.3494	0.0349
DR	0.0471	0.0537	0.0291	0.0278	0.0274	0.0811	0.0312	0.0706	0.0447	0.0833	0.4961	0.0496
CS	0.0471	0.023	0.0194	0.0278	0.0274	0.0135	0.0208	0.0118	0.0149	0.0277	0.2335	0.0233

Table 5. Order of priority sub-criteria.

No.	Sub-Criteria	Priority Vector
1	Wind Speed (WS)	0.2871
2	Wind Density (WD)	0.1837
3	Slope (SP)	0.1096
4	Elevation (EL)	0.1081
5	Land Use (LU)	0.0850
6	Distance to Networks (DN)	0.0723
7	Distance to Roads (DR)	0.0496
8	Distance to Airports (DA)	0.0459
9	Distance to Urban Places (UP)	0.0349
10	Cost (CS)	0.0233

3.2. Selection of alternative location for wind power plant

In selecting the right Wind Power Plant location, the researchers adjusted the location selection based on the priority level obtained. The data on the proposed alternative locations were obtained through the Annual Report of the Development of the Integrated Marine and Fisheries Center, East Sumba Regency in 2018, Global Wind Atlas, RPI2JM (Review of Medium-Term Infrastructure Investment Plan) East Sumba Regency, Integrated Marine and Fisheries Center Masterplan (SKPT) East Sumba Regency, Central Statistics Agency (BPS). The criteria include wind speed, wind density, slope, elevation, land use, distance to networks (power grid or sub-station), distance to roads, distance to airports, distance to urban places, and cost.

Fuzzy-TOPSIS calculation results

After determining the results of the priority order of the sub-criteria using the AHP method, the results of the priority order for each sub-criteria are used as the weight of the assessment in the Fuzzy-TOPSIS method, then determine the costs or benefits for each sub-criterion. If a sub-criterion has a higher value, the better or more profitable it is, then the sub-criteria is included in the benefit category and if a sub-criterion has a higher value, the lower or the disadvantage is then the sub-criteria is included in the cost category. The weight of the assessment for each sub-criteria can be seen in Table 6.

Table 6. Weights and categories of sub-criteria from the calculation results of the AHP method.

	WS	WD	SLP	EL	LU	DN	DR	DA	DUP	CST
Weight	0.2871	0.1837	0.1096	0.1081	0.085	0.0723	0.0496	0.0459	0.0349	0.0233
Category	benefit	benefit	cost	benefit	cost	cost	cost	benefit	benefit	cost

After obtaining the weight value for each sub-criteria, then assigning a weighting rating to each sub-criteria for the two alternative locations of Wind Power Plant using a Triangular Fuzzy Number (TFN) assessment. Table 7 shows the fuzzy decision matrix

Table 7. Fuzzy decision matrix.

	Pamburu Village			Kadahang Village		
	l	**m**	**u**	**l**	**m**	**u**
WS	3	5	7	7	9	9
WD	3	5	7	7	9	9
SLP	7	9	9	5	7	9
EL	3	5	7	3	5	7
LU	7	9	9	5	7	9
DN	1	1	3	1	1	3
DR	7	9	9	7	9	9
DA	7	9	9	7	9	9
DUP	7	9	9	7	9	9
CST	1	1	3	1	1	3

3.3. Discussion

In the AHP method, calculations are done manually in Microsoft Excel and using Expert Choice software. The consistency of calculations in the AHP method both has the same final result, namely the Consistency Ratio (CR) value of 0.09 or 9%.

With the consistency value, it proves that the results obtained are acceptable and the calculation is said to be consistent because 9% is smaller than 10% which is the standard limit of the consistency ratio value in the AHP method [28]. This proves that the results of the calculation of the AHP method by the researcher are correct. The results also found that wind speed and wind density are the two sub-criteria with the highest priority order, meaning that these two sub-criteria are highly considered, this is also found in research [23] which shows that wind speed is a determining factor for decisions, followed by wind density.

By using the Fuzzy-TOPSIS method, the selection of alternative locations based on the ten selected sub-criteria is determined. Researchers chose two locations in East Sumba Regency, namely Pamburu Village in Pahunga Lodu District and Kadahang Village in Haharu District. The two locations were proposed by researchers because East Sumba Regency has a fairly high availability of wind energy, in line with research [29] which says that the availability of wind natural resources in East Sumba has a fairly high value. By using the Fuzzy-TOPSIS method, from the two proposed alternative locations that have the potential for establishing a Wind Power Plant, the researcher will determine one of the locations that has the potential. For the sub-criteria Wind Speed (WS) and Wind Density (WD) Kadahang Village, Haharu District has the potential for higher wind speed and wind density than Pamburu Village, Pahunga Lodu District. Kadahang Village has a wind speed of 6.20 m/s and a wind density of 201 W/m^2, both sub-criteria wind speed and wind density in Kadahang Village are included in the very high category. For the Slope (SP) and Land Use (LU) sub-criteria, Pamburu Village, Pahunga Lodu District has very good land slope and land use potential. In Pamburu Village the slope of the land is dominated by a slope of 0-8° and for land use in Pamburu Village the average is dominated by grasslands which are included in the Non Forest Area (NFA) category. Meanwhile, the sub-criteria for Elevation (EL), Distance to Network (DN), Distance to Roads (DR), Distance to Airports (DA), Distance to Urban Places (UP) and Cost (CS) in Pamburu Village and Kadahang Village are both have the same weighted Triangular Fuzzy Number (TFN) assessment. From the results of the calculation of the Fuzzy-TOPSIS method, it is found that with a preference value of 0.9264, Kadahang Village, Haharu District is ranked first, which means that Kadahang Village has more potential and is more suitable as a location for the establishment of Wind Power Plant compared to Pamburu Village, Pahunga Lodu District which occupies second rank with a preference value of 0.0736.

The findings and discussion obtained by the researchers become a new reference and alternative in helping to determine the location of the power plant with a multi-criteria decision-making approach based on the AHP method and the Fuzzy-TOPSIS method. The AHP method is the only methodology that can consider the consistency of decision makers and the main advantage of this method is that it is relatively easy to handle many criteria and can be applied to both qualitative and quantitative data [14, 16, 19]. And the Fuzzy-TOPSIS method has the ability to rank the best alternatives quickly, where this method works based on the principle of compromise and has the ability to handle conflicting situations [14, 17, 18]. The results of this study are expected to provide benefits for engineering consultants and the method used can be used as a reference in decision making to be developed by other researchers. However, this study has limitations that the data obtained are obtained in the literature and the criteria chosen are only based on the opinions of experts who use it a lot without conducting direct interviews. It would be better if the research was carried out by making direct observations in the field for more precise and accurate results in accordance with the original conditions in the field.

4. Conclusions

Based on calculations using the AHP method, the priority order of sub-criteria is obtained, namely Wind Speed (WS) as the first priority, Wind Density (WD) as the second priority, followed by Slope (SP), Elevation (EL), Land Use (LU), Distance to Networks (DN), Distance to Roads (DR), Distance to Airports (DA), Distance to Urban Places (UP), and Cost (CS) as the last order of priority. Calculations on the AHP method are done manually in Microsoft Excel and Expert Choice software. The value of Consistency Ratio (CR) is 0.09 or 9%. The calculation results are said to be consistent because the 9% CR value is smaller than 10% which is the standard limit for the consistency ratio value in the AHP method. In the Fuzzy-TOPSIS method, two potential locations in East Sumba Regency, namely Pamburu Village in Pahunga Lodu District and Kadahang Village in Haharu District are proposed as alternative locations for Wind Power Plant. By using the Fuzzy-TOPSIS method based on ten selected sub-criteria, the feasibility of the alternative location of Wind Power Plant was obtained with a preference value of 0.9264 in Kadahang Village, Haharu sub-district is ranked first, which means that Kadahang village has more potential and is more suitable to be used as a location for the establishment of Wind Power Plant compared to Pamburu village, Pahunga Lodu sub-district which is in second place with a preference value of 0.0736.

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