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GIS-based simulation for wind farm site suitability analysis: A systematic review

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Keywords: Combination of criteria, literature review, location choice, multi-criteria decision analysis.

Abstract: This study aims at conducting a literature review on GIS-based simulation for suitable onshore wind farm site selection. A total of 58 papers, which is published in 2010 to 2024 and from high-quality journals, were manually collected, investigated, and classified into the following categories: year of publication, keyword, journal index, application area, employed software, applied multi-criteria decision-making method, and proposed criteria. The top ten of the most used criteria were analysed in detail to indicate their importance order as well as value categories, potential value, restrictive value. Specifically, the criteria in the articles were the result of research conducted in different natural and economic climate zones in the world. Moreover, from these ten criteria, this study also determined combinations of criteria which simultaneously appeared the most in the collected papers. The set of criteria includes points of intersection and convergence of important characteristics of natural conditions and socio-economic infrastructure that significantly influence the decision on selecting the optimal location. The results showed that "distance from road network" was the most preferred criterion while "wind speed" was considered as the most important criterion. Furthermore, a combination of two criteria "wind speed" and "distance from road network" was the most used with a frequency of 50 (in total of 58 times). As the results, the research contributed a set of useful and necessary information for making decisions on suitable wind farm site selection which may help researchers, local government, investors easily determine and choose relevant influenced criteria and suitable methods.

1. INTRODUCTION

Energy is a key element for economic and society development of a country in specific and of the world in general. Goods manufacture and services significantly depend on energy. However, natural fossil fuel resources, such as oil and coal are not distributed evenly around the world, and they are in danger of running out. Moreover, the environmental problems, such as air pollution, water pollution, and solid waste disposal directly related to energy production and consumption by exploitation and using these fossil fuels were reported in many places around the world. The reports from "Statistical Review of World Energy" pointed out that carbon dioxide emissions from energy fell by 6.3% in 2020 (Statistical Review of World Energy, 2021), rising 5.9% to 33.9 GtCO2e in 2021 (Statistical Review of World Energy, 2022), 0.9% to 34.4 GtCO2e in 2022 (Statistical Review of World Energy, 2023), 35GtCO2e in 2023 (Statistical Review of World Energy, 2024), 1% to 40.8 GtCO2e in 2024 (Statistical Review of World Energy, 2025) comparing to that of previous year. During the covid-19 pandemic, "work from home" was applied in many countries and activities relating to using fossil fuel significantly decreased. It was reported that energy consumption in 2020 decreased by 4.5% which is the largest decline since 1945 (Statistical Review of World Energy, 2021) while in later years, the energy consumption increased from 1 to 5.8% comparing to previous year in 2021, 2022, 2023, 2024 (Statistical Review of World Energy, 2022; 2023; 2024; 2025). This resulted in remarkable environmental improvement compared with that before covid-19 pandemic: the carbon dioxide emissions from energy use decreased by 6.3 % in 2020 (Statistical Review of World Energy, 2021) compared to that of previous year. That is a very clear and typical example of the impact of using fossil fuel on the environment. From above explanation, renewable energy resources with unlimited capacity and environmental friendliness will be the best optimal solution for sustainable development in the future (Zhang, Shen, et al., 2013; Wang, Peng, et al., 2015; Puteri, Yuli, et al., 2026). Recently, according to natural geographic condition suitability, many countries applied different renewable energy resources for electricity generation, such as ocean, biomass, solar, wind, and so on. It was reported that the solar and wind capacity continued to grow rapidly with an increase of 238 GW in 2020, 226 GW in 2021, 266 GW in 2022, 462 GW in 2023, and 500GW in 2024 respectively. This development trend matches the "Goal 7- Ensure access to affordable, reliable, sustainable, and modern energy for all" from "the 17 Sustainable Development Goals" which means that wind and solar farms development is necessary and urgent toward sustainable development (The 17 Sustainable Development Goals). At present, China emerged as a country which was the largest individual contributor to solar and wind capacity growth in 2020, 2021, 2022, 2023, and 2024.

Due to rapid increase of capacity from renewable energy sources, such as solar and wind energy, each country and local government should have suitable plans and strategies to take full advantage of these available sources. Furthermore, for each renewable energy project, such as wind energy farm, investigation and construction will cost a lot of money and time. Therefore, suitable site selection plays an important work for the whole project which require careful consideration and estimation on many aspects and criteria. In most selected papers from literature, these criteria were suggested and evaluated by experts from related fields and local government. However, in some cases, the authors decided the criteria by themselves based on reviewing other papers in the same subject (T. M. T. Nguyen, D. T. Nguyen, et al., 2020; D. T. Nguyen, Truong, et al., 2022a; D. T. Nguyen, Truong, et al., 2022b). This method could provide useful and necessary information on criteria for wind farms sitting in different regions and countries. Until now, there are several studies which conducted a systematic literature review on wind farm site selection (Rediske, Burin, et al. 2021; Joshua, Chinedu, et al., 2023; Tsani, Michael, et al., 2024). Rediske, Burin, et al. (2021) clarified restrictive, relevant criteria, and methods for wind farm site selection. Joshua, Chinedu, et al. (2023) reviewed about 116 papers including onshore (95 papers) and offshore (21 papers) wind farms for analysing 15 most common sitting factors for each type of wind farm. This study also classified criteria into constraint criteria and evaluation criteria and examined their frequency as well as summarized methods used for location choice models. Finally, Tsani, Michael, et al. (2024) focused on existing quantification of social factors for onshore wind power and methods for integrating these factors into planning models. These three studies did not analyse criteria in detail by describing their optimal and restrictive values and value categories, and did not order their importance (weight), as well as pointed out combinations of criteria appeared simultaneously. Therefore, different from literature, in this study, ten criteria, which were mostly preferred among used criteria from 58 selected papers, were analysed in detail to clarify following information: importance order, value categories, potential value, restrictive values. Moreover, the study also determined the combinations of criteria which simultaneously appeared most in the papers.

Form above explanation, the purpose of this research is to review research papers on GIS-based simulation for suitable onshore wind farm site selection for identifying the most used criteria as well as determining combination of criteria which simultaneously appeared. The analytic results will support researchers, local government, investors easily making decisions on determining and choosing relevant influenced criteria for wind farm siting.

This paper is laid out as follows: methodology is presented in Section 2, followed by the results and discussion in Section 3. Conclusion is made in Section 4.

2. METHOD

This research proposed a procedure to collect journal papers and analysed criteria as shown in *Figure 1* which includes two steps. At the first step, keywords which were consist of "wind farm location, wind farm sitting", were selected and searched via popular database sources "Science direct, Google Scholar" firstly. By manually checking the tittle one by one, around 120 research papers which were published from 2001 to 2024, were collected and downloaded. Secondly, a question "did an article discuss onshore or offshore wind energy farm?" was applied to 120 papers to determine unrelated studies. Articles of "offshore wind farm" were eliminated while articles of "onshore wind farm" went through the next round. Thirdly, another question "did an article present, discuss and analyse criteria for onshore wind farm sitting" was applied by reading the abstract and skimming the full text one by one which resulted in eliminating unrelated articles. The final satisfied number of articles for the review at the end of first step was 58 which went to the next step for advanced analysis. In the second step, the full text read in detail was applied to analysed categories: year of publication, keyword, journal index, application area, employed software, applied multi-criteria decision-making method and proposed criteria. A manual statistic method in Excel software was employed to analyse above categories. Moreover, the top ten used criteria were analysed in detail which showed information on importance order, value categories, potential value, restrictive value for each criterion. Finally, the combinations of criteria, which appeared simultaneously, were also estimated.

The detailed methods for analysing importance order and combination of criteria were presented in section 3.6 and 3.7.

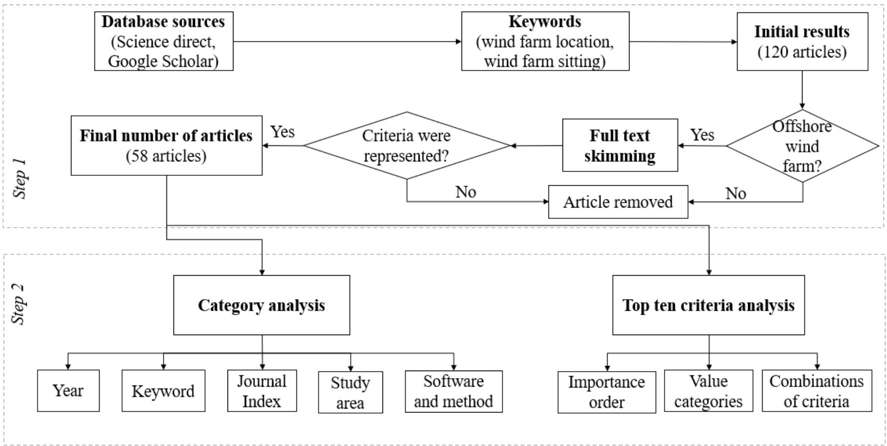

Figure 1. A procedure for collecting articles and category analysis

3. RESULTS AND DISCUSSION

3.1 Year of publication

The information on year of paper publication indicates whether topic is still hot research topic and is updated frequently. In this research, most of selected journal papers were published between 2015 and 2024 and there was only one paper pulished in 2010 (*Figure 2*). Moreover, in the recent 10 years, the number of papers significantly increased from 2 papers in the year of 2012 to 14 in 2023.

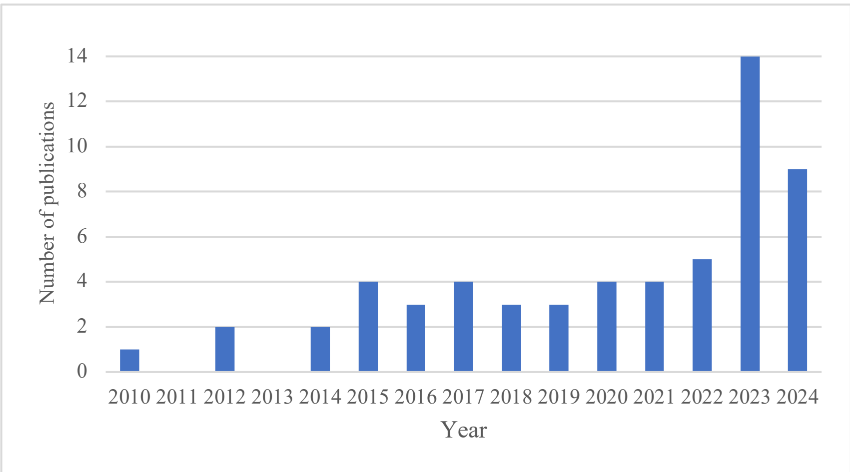

Figure 2. Number of publications per years

3.2 Keywords

Keywords play an important role in helping readers to find expected papers easily. There were 104 used separate keywords (*Figure 3*) which appeared with different frequencies in the 58 selected papers. Among of them, “GIS”, "Wind energy", and "Name of cities or countries (case study)" were the most used as the keywords with the number of frequencies of 37, 20, 20 respectively. The following ones are keywords relating to methodologies, such as "Multi-criteria decision making (MCDM)", "Analytic hierarchy process", "AHP", "Multi-criteria decision analysis (MCDA)". The list of top 10 used keywords was represented in *Table 1*.

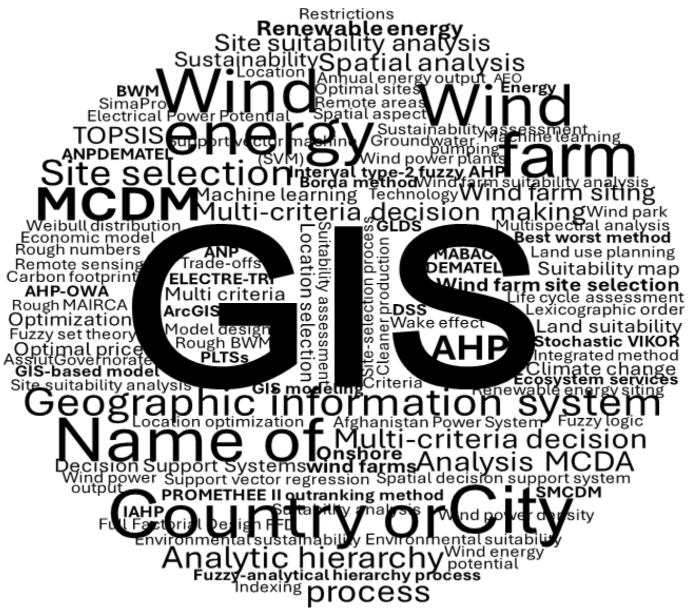

Figure 3. Cloud illustration of the keywords (obtained on October 4th, 2025)

Table 1. Top 10 most used keywords

No.	Keyword	Frequency
1	GIS	37
2	Wind energy	20
3	Name of city/country	20
4	Wind farm	19
5	Multi-criteria decision making (MCDM)	17
6	Geographic information system	15
7	Site selection	14
8	AHP	13
9	Analytic hierarchy process	13
10	Multi-criteria decision analysis (MCDA)	4

3.3 Journal information

Journal information, which includes journal index, journal impact factor, and journal quartile, indicates how good the journal is as well as how good the input data is for analysis in this research. The 58 selected papers belong to 25 Web of Science research journals which include 23 SCIE indexed journals (55 papers) and 2 ESCI indexed journals (3 papers) (*Figure 4a*). Among of them, the two journals, "Renewable energy" and "Energy", have the greatest number of papers which are 9 and 8 respectively (*Figure 5*). Moreover, the journal quartile ranges from Q1 to Q3 which corresponds to 17, 7, and 1 journals respectively. 24/25 journals were Q1 and Q2 journals while more than 68 percentages of them were Q1 journals (*Figure 4b*). In addition, around 69 percent of publications come from the journals which have the impact factor more than 5 (*Figure 4c*) and the journal namely "Renewable and

Sustainable Energy Review" has the highest impact factor of 16.3 among the selected journals. The summarized information on journals was presented as *Figure 5*. The statistics above proved that all collected publications come from journals which are very high-quality journals and they are very good input data for the analysis in this study.

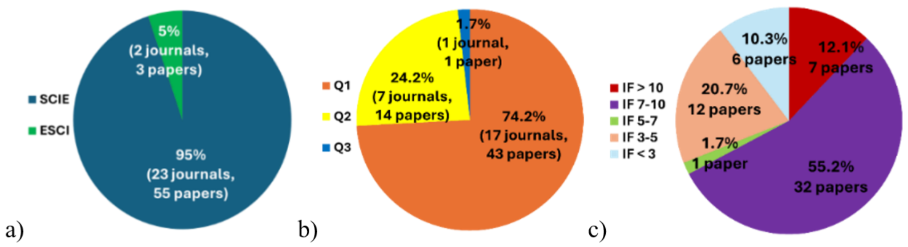

Figure 4. Journal information: a) journal index; b) journal quartile; c) journal impact factor

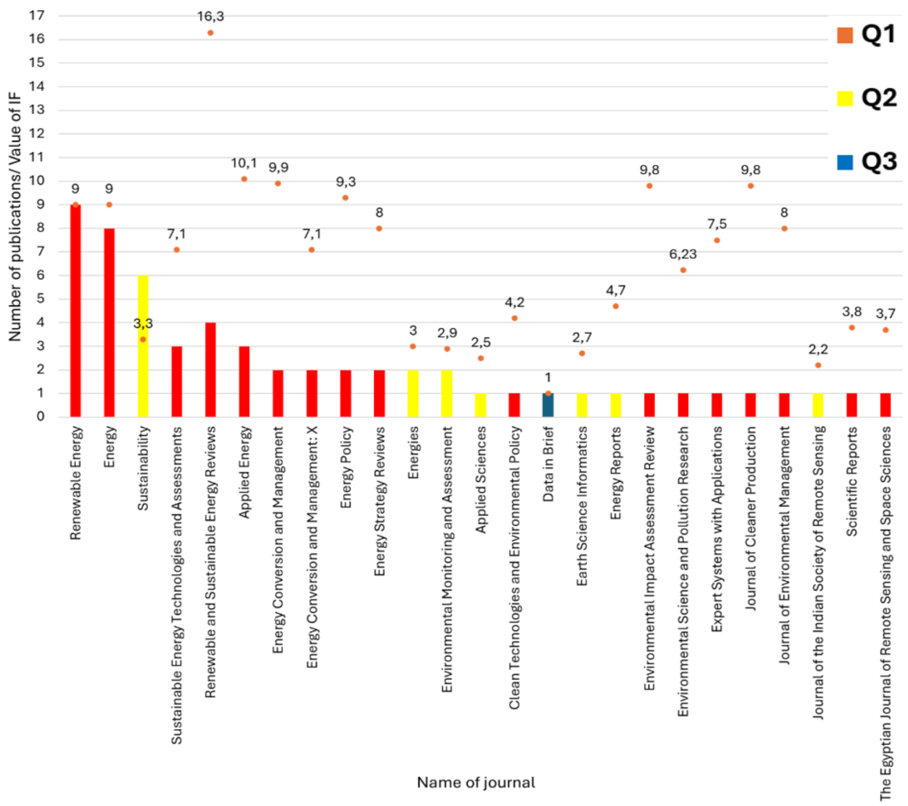

Figure 5. Detailed Information of journals from collected papers: name of journal; number of publications, impact factor score, quartile of each journal

3.4 Application area

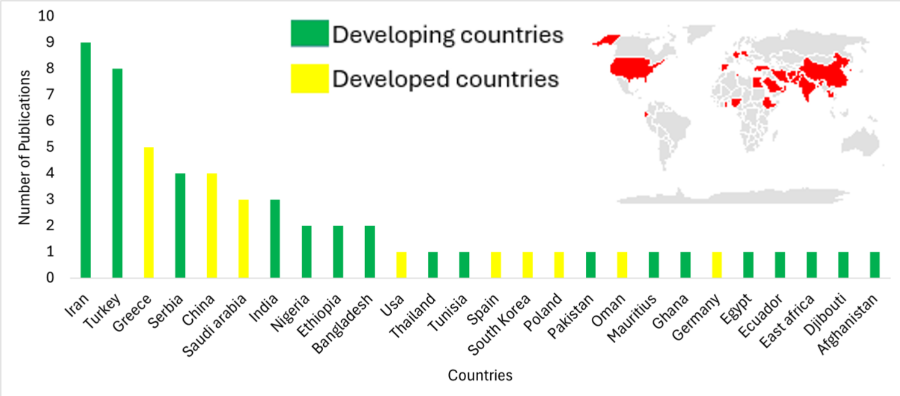

Figure 6. Distribution of the countries where problems are considered in the red colour on the world map

The studies on wind farm site selection were applied in various regions around the world such as Asia, Europe, Africa, South and North America as well as from the developing to developed countries (*Figure 6*). Among of them, the two countries, Iran and Turkey, were considered as case studies by most studies which are 9 and 8 respectively. The above result shows that using wind power electric is a global energy development trend.

3.5 Software and Methods for wind farm site selection

Until now, there were a lot of commercial GIS software which were employed to conduct spatial analysis for wind farm site suitability. Among them, ArcGIS emerged as the most popular and used software for wind farm sitting from the selected papers. Although 8 papers did not mention the name of the software used, they were conducted in GIS environment. *Table 2* represented applied software which was used to compile geographic data, analyse mapped information, create theme maps, and present the results as maps.

Table 2. Software used in collected papers

Software	Fre-quency	Reference
ArcGIS	46	Xing and Wang (2021); Baseer, Rehman, et al. (2017); Gigović, Pamučar, et al. (2016); Ali, Taweekun, et al. (2018); Tercan (2021); Saraswat, Digalwar, et al. (2021); Moradi, Yousefi, et al. (2020); Noorollahi, Yousefi, et al. (2016); Cunden, Doorga, et al. (2020); Ayodele, Ogunjuyigbe, et al. (2018a); Anwarzai and Nagasaka (2017); Höfer, Sunak, et al. (2016); Villacreses, Gaona, et al. (2017); Bina, Jalilinasrabady, et al. (2018); Konstantinos, Georgios, et al. (2019); Al-Yahyai, Charabi, et al. (2012); Gorsevski, Cathcart, et al. (2013); Koc, Turk, et al. (2019); Tegou, Polatidis, et al. (2010); Jangid, Bera, et al. (2016); Ali, Lee, et al. (2017); Pamučar, Gigović, et al. (2017); Gao, Wang, et al. (2022); Shorabeh, Firozjaei, et al. (2022); Islam, Islam, et al. (2022); Effat and El-Zeiny (2022); Nagababu, Puppala, et al. (2022); Amjad, Agyekum, et al. (2021); Asadi, Ramezanzade, et al. (2023); Dinçer, Demir, et al. (2023); Albraheem, L., AlAwlaqi, L. (2023); Asadi, Pourhossein, et al. (2023); Yegizaw and Mengistu (2023); Josimovic, Srnic, et al.(2023); Rekik and Alimi (2023); Raza, Yousif, et al. (2023); Benti, Alemu, et al. (2023); Aghaloo, Ali, et al. (2023); Yaman (2024); Bimenyimana,

		Wang, et al. (2024a); Yildiz (2023); Demir, Riaz, et al. (2024); Salih, Hassaballa, et al. (2024); Demir, Dinçer, et al. (2024); Abdi, Damci, et al. (2024); Bimenyimana, Wang, et al. (2024b).
QGIS	2	Potić, Joksimović, et al. (2021); Amsharuk and Łaska (2023).
gvSIG	1	Sanchez-Lozano, García-Cascales, et al. (2014).
Mapinfo	1	Latinopoulos and Kechagia (2015).
GIS environment (Not mentioned specified software)	8	Ayodele, Ogunjuyigbe, et al. (2018a); Xu, Li, et al. (2020); Azizi, Malekmohammadi, et al. (2014); Rezaian and Jozi (2016); Karamountzou and Vagiona (2023); Sotiropoulou, Vavatsikos, et al. (2023); Yousefi, Moradi, et al. (2024); Bilgili, Arda, et al. (2024).

The integration between GIS and multi-criteria decision analysis (hereafter, MCDA) is considered as the most popular method for location choice simulation / models in general and for wind farm sitting in specific. In this method, after proposing a list of criteria and sub-criteria, the MCDA is applied to determine the relative weight (importance level) of each criterion. Furthermore, among MCDA methods, the analytic hierarchy process (AHP) is considered as the simplest and most popular one which is characterized by pairwise comparison of criteria and the matrix of these pairwise comparisons. Apart from AHP, an integration between AHP and another technic, such as ELECTRE III, ANP, and so on were also employed. *Table 3* showed methods applied in the literature.

Table 3. Applied methods for site selection

Method	**Fre-quency**	**Reference**
AHP	27	Baseer, Rehman, et al. (2017); Ali, Taweekun, et al. (2018); Moradi, Yousefi, et al. (2020); Cunden, Doorga, et al. (2020); Potić, Joksimović, et al. (2021); Höfer, Sunak, et al. (2016); Koc, Turk, et al. (2019); Tegou, Polatidis, et al. (2010); Jangid, Bera, et al. (2016); Rezaian and Jozi (2016); Islam, Islam, et al. (2022); Effat and El-Zeiny (2022); Amjad, Agyekum, et al. (2021); Asadi, Ramezanzade, et al. (2023); Dinçer, Demir, et al. (2023); Albraheem and AlAwlaqi (2023); Yegizaw and Mengistu (2023); Rekik and Alimi (2023); Raza, Yousif, et al. (2023); Benti, Alemu, et al. (2023); Yaman (2024); Bimenyimana, Wang, et al. (2024b); Yildiz (2023); Salih, Hassaballa, et al. (2024); Demir, Dinçer, et al. (2024); Yousefi, Moradi, et al. (2024); Bimenyimana, Wang, et al. (2024)
F-AHP	3	Latinopoulos and Kechagia (2015); Saraswat, Digalwar, et al. (2021); Ali, Lee, et al. (2017)
Multi-criteria decision support MCDA	3	Noorollahi, Yousefi, et al. (2016); Anwarzai and Nagasaka (2017); Bina, Jalilinasrabady, et al. 2018)
AHP-TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)	3	Konstantinos, Georgios, et al. (2019); Karamountzou and Vagiona (2023); Amsharuk and Łaska (2023)
Interval Type 2 Fuzzy AHP	2	Ayodele, Ogunjuyigbe, et al. (2018a); Ayodele, Ogunjuyigbe, et al. (2018b)
Best Worst Method (BWM)	2	Tercan (2021); Shorabeh, Firozjaei, et al. (2022)

Method	Frequency	Reference
Fuzzy Analytic Hierarchy Process and Weighted Slacks-based Measure	1	Xing and Wang (2021)
DEMATEL, ANP, and MABAC	1	Gigović, Pamučar, et al. (2016)
ELECTRE-TRI	1	Sanchez-Lozano, García-Cascales, et al. (2014)
IAHP (interval AHP) and Sochatics VIKOR	1	Xu, Li, et al. (2020)
AHP-OWA (ordered weighted averaging)- OCRA (Occupational Repetitive Actions) - VIKOR-TOPSIS-OPI (overall Performent Index)	1	Villacreses, Gaona, et al. (2017)
AHP-OWA	1	Al-Yahyai, Charabi, et al. (2012)
Spatial Decision Support System	1	Gorsevski, Cathcart, et al. (2013)
ANP and DEMATEL	1	Azizi, Malekmohammadi, et al. (2014)
Rough-based Best-Worst method (R-BWM) and MultiAttributive Ideal-Real Comparative Analysis (MAIRCA)	1	Pamučar, Gigović, et al. (2017)
DEMATEL (Decision-Making and Trail Evaluation Laboratory) and GLDS (Gain and Lost dominance scores)	1	Gao, Wang, et al. (2022)
F-AHP and TOPSIS	1	Nagababu, Puppala, et al. (2022)
Support vector regression (SVR) and AHP	1	Asadi, Pourhossein, et al. (2023)
PROMETHEE Methods	1	Josimovic, Srnic, et al.(2023)
The Fuzzy logic, Boolean logic and BWM	1	Aghaloo, Ali, et al. (2023)
AHP and PROMETHEE	1	Sotiropoulou, Vavatsikos, et al. (2023)
Fuzzy Stepwise Weight Evaluation Ratio Analysis (F-SWARA) and Measurement Alternatives and Ranking by Compromise Solution (F-MARCOS)	1	Demir, Riaz, et al. (2024)
Machine learning (ML) algorithms	1	Bilgili, Arda, et al. (2024)
CRITIC (Criteria Importance Through Intercriteria Correlation)	1	Abdi, Damci, et al. (2024)

3.6 Proposed criteria

The wind farm project requires a big investment cost and a long time for construction. Therefore, to select the most suitable site for windfarm, many relevant criteria should be considered and estimated carefully. This results in maximizing economic interest and minimizing impact on the environment and society. According to 58 collected publications, there were 64 criteria proposed by the authors which appeared in different numbers of publications (*Table 4*). Among these criteria, the top 10 criteria with highest frequency will be analysed in detail and ordered according to their importance.

From table 4, distance from road network, wind speed, slope, distance from transmission lines, distance from residential area, land use, distance from natural and protected area, elevation, distance from surface water, distance from airports, are 10 criteria which were used the most in selected papers. Because of wind farm sitting, the wind speed was considered as the most important criterion in most of selected papers. Other nine criteria appeared with different relative weight (importance level) case by case. In other words, some criteria were very important in several studies but less important in the other ones. Therefore, this research also proposed a method for determining the weight of each criterion in order as follows: Firstly, the order of weight of ten criteria of each paper was determined based on their value of weight which were estimated by that paper's authors. Secondly, the criterion with the highest weight got score of ten and vice versa the criterion with lowest weight got score of one (*Table 5*). A sum of score of each criterion in all selected papers, then, was calculated using the *Equation 1*. Finally, the weight order was determined by comparing the total scores among criteria. As a result, the order of weight of criteria was as follows: wind speed, distance from transmission lines, distance from roads, slope, distance from settlements, land use, elevation, distance from natural area and protected areas, distance from airport, and distance from water bodies (*Figure 7*).

$$TS_i = S_{i1} + S_{i2} + \cdots + S_{i58} \tag{1}$$

TSi: total score of criterion i; S_{i1}: score of criterion i in paper 1; S_{i2}: score of criterion i in paper 2; S_{i58}: score of criterion i in paper 58;

Table 4. Criteria used in 58 publications

No.	Criteria	Frequency
1	Distance from road network	56
2	Wind speed	52
3	Slope	51
4	Distance from transmission lines	46
5	Distance from residential areas	43
6	Land Use	33
7	Distance from natural and protected area	23
8	Elevation	19
9	Distance from surface water	13
10	Distance from airport	12
11	Distance from electricity transformer substations	8
12	Distance from historical and tourism sites	7
13	Wind Power Density	7
14	Distance from railway	7
15	Distance from Fault	5
16	Aspect	5
17	Population density	4
18	Geological rock/soil types	4
19	Bird migration paths	4
20	Area	3
21	Distance from protected bird areas	3
22	Terrain ruggedness	3
23	Telecommunication infrastructure	2
24	Distance from power plants	2
25	Distance from sandune	2
26	Visual impact	2
27	Distance from infrastructure electricity	2
28	Resident acceptance	2
29	Distance from coastline	2
30	Landscape architecture	2
31	Air density	2
32	Distance from seaports	2
33	Annual Energy Output	1
34	Wind Power Output	1
35	Turbulence intensity	1
36	Peak hours matching	1
37	Electricity demand	1
38	Land value	1
39	Lightning strike flash rate	1
40	Wake penalty	1
41	Installed Capacity	1
42	Year of Operation	1
43	Number of Wind Turbines	1
44	Natural Hazards	1
45	Distance from Rocky land	1
46	Proximity to industrial area and mining zone;	1

No.	Criteria	Frequency
47	The distance from livestock plants	1
48	Distance to irrigated areas	1
49	Distance to secure from threats	1
50	The distance from non-compatible areas	1
51	Rainfall	1
52	Distance from disaster centers	1
53	Distance from Aquifer potential source	1
54	CO2 emission	1
55	Distance to landslide zones	1
56	Changes in wind direction	1
57	Scale of energy storage	1
58	Energy storage investment cost	1
59	Dynamic payback period	1
60	Carbon emission reduction	1
61	Number of frosty days during the year	1
62	Distance from traffic infrastructure	1
63	Land ownership	1
64	Seismicity	1

Table 5. Score according to the importance of the criteria

Ranking	1	2	3	4	5	6	7	8	9	10
Score	10	9	8	7	6	5	4	3	2	1

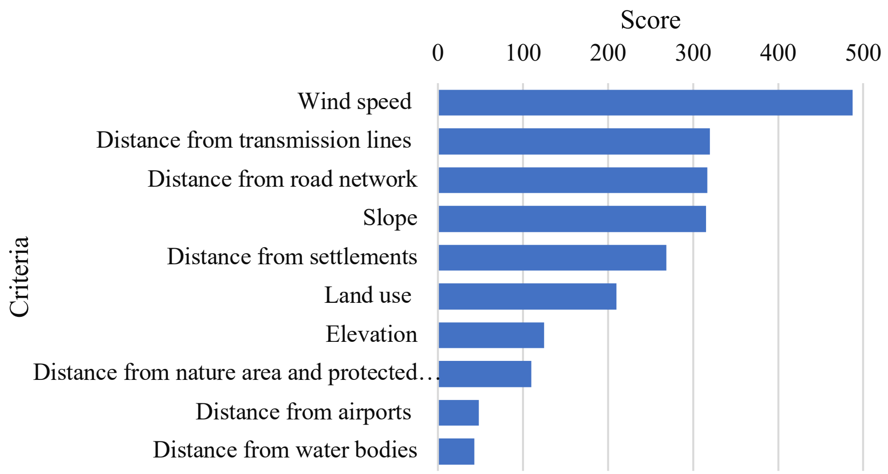

Figure 7. Order of importance of top 10 criteria based on total score

In the following parts, these top ten criteria will be described in detail which indicates value categories, potential value, restrictive value of each criterion.

3.6.1 Wind speed

Wind speed is the main criterion with highest weight for wind farm sitting in almost reviewed studies. There are several sources for obtaining the free data on wind speed which were used in the literature, such as, “Global Wind Atlas - https://globalwindatlas.info/en/”. These data were represented as shape files which could be used easily and directly for spatial analysis.

Apart from above free data source, many authors also applied survey data on wind speed at 10m and then converted to wind speed with expected heights

From the 58 selected papers, many authors suggested optimal wind speed as 6m/s, 7m/s while restrictive wind speeds were set as less than 3m/s, 5m/s.

A detailed information on values of optimal and restrictive wind speed as well as categories of wind speed was presented in *Table 6*.

Table 6. Distribution wind speed at height

	Value (m/s)	**Reference**
Optimal wind speed	>5	Gigović, Pamučar, et al. (2016); Villacreses, Gaona, et al. (2017); Shorabeh, Firozjaei, et al. (2022).
	>6	Baseer, Rehman, et al. (2017); Ali, Taweekun, et al. (2018); Saraswat, Digalwar, et al. (2021); Anwarzai and Nagasaka (2017); Bina, Jalilinasrabady, et al. (2018); Islam, Islam, et al. (2022); Nagababu, Puppala, et al. (2022); Amjad, Agyekum, et al. (2021); Yaman (2024); Demir, Riaz, et al. (2024).
	>7	Ayodele, Ogunjuyigbe, et al. (2018a); Sanchez-Lozano, García-Cascales, et al. (2014); Ayodele, Ogunjuyigbe, et al. (2018b); Höfer, Sunak, et al. (2016); Gorsevski, Cathcart, et al. (2013); Effat and El-Zeiny (2022); Dinçer, Demir, et al. (2023); Albraheem, L., AlAwlaqi, L. (2023); Raza, Yousif, et al. (2023); Aghaloo, Ali, et al. (2023); Demir, Dinçer, et al. (2024); Abdi, Damci, et al. (2024).
	>8	Moradi, Yousefi, et al. (2020); Rekik and Alimi (2023); Yildiz (2023); Bilgili, Arda, et al. (2024).
Excluded wind speed	<3	Saraswat, Digalwar, et al. (2021); Pamučar, Gigović, et al. (2017); Nagababu, Puppala, et al. (2022); Dinçer, Demir, et al. (2023); Aghaloo, Ali, et al. (2023); Yaman (2024); Demir, Riaz, et al. (2024); Demir, Dinçer, et al. (2024); Abdi, Damci, et al. (2024).
	<4	Ali, Taweekun, et al. (2018); Rezaian and Jozi (2016); Islam, Islam, et al. (2022); Amjad, Agyekum, et al. (2021).
	<4,4	Ayodele, Ogunjuyigbe, et al. (2018a); Tercan (2021); Ayodele, Ogunjuyigbe, et al. (2018b); Albraheem, L., AlAwlaqi, L. (2023); Bilgili, Arda, et al. (2024).
	<5	Baseer, Rehman, et al. (2017); Villacreses, Gaona, et al. (2017); Konstantinos, Georgios, et al. (2019); Al-Yahyai, Charabi, et al. (2012); Koc, Turk, et al. (2019); Tegou, Polatidis, et al. (2010); Shorabeh, Firozjaei, et al. (2022); Rekik and Alimi (2023); Raza, Yousif, et al. (2023).
	<5,6	Moradi, Yousefi, et al. (2020); Noorollahi, Yousefi, et al. (2016); Gorsevski, Cathcart, et al. (2013); Yegizaw and Mengistu (2023); Yousefi, Moradi, et al. (2024).
	<6	Anwarzai and Nagasaka (2017); Höfer, Sunak, et al. (2016); Bina, Jalilinasrabady, et al. (2018).
Range	<3; 3-4; 4-5; 5-6; >6	Saraswat, Digalwar, et al. (2021); Nagababu, Puppala, et al. (2022); Demir, Riaz, et al. (2024).
	<3; 3-4; 4-5; 5-6; 6-7; 7-8; >8	Moradi, Yousefi, et al. (2020); Abdi, Damci, et al. (2024).
	<4,4; 4,4-5,1; 5,1-5,6; 5,6-6; 6-6,4; 6,4-7; >7	Ayodele, Ogunjuyigbe, et al. (2018a); Tercan (2021); Ayodele, Ogunjuyigbe, et al. (2018b).
	<5; 5-6; 6-7; 7-8; >8	Rekik and Alimi (2023); Yildiz (2023).
	<5,6; 5,6-6,4; 6,4-6,9; 6,9-7,5; 7,5-9; >9	Noorollahi, Yousefi, et al. (2016); Yousefi, Moradi, et al. (2024).

3.6.2 Proximity to transmission line

A long distance from the wind farm sites to existing transmission lines results in high cost and electricity losses. Therefore, the closer the distance is, the higher the advantage is. However, because of height of wind turbines, a restrictive distance from the transmission lines should be identified to make all things safe. From the selected publications, the minimum restricted distances were various, such as, 100m, 200m, 250m, 300m, 500m, and 600m while the maximum restricted distances were set as 2km, 2.5km, 5km, 7.5km, 10km, 15km, 20km, 40km, 50km, and 132km. Moreover, the literature also pointed out that the most optimal distances for setting the wind farm were 250m-5,000m. *Table 7* also summarized values of optimal distances, restrictive distances and the distance categories from transmission lines which were mentioned the most from selected publications.

Table 7. Distribution proximity to transmission lines for wind farm site selections

	Value (km)		Reference
Optimal distances	0 – 0.5		Gigović, Pamučar, et al. (2016); Koc, Turk, et al. (2019); Tegou, Polatidis, et al. (2010)
	0.25 – 5		Ayodele, Ogunjuyigbe, et al. (2018a); Ayodele, Ogunjuyigbe, et al. (2018b); Yegizaw and Mengistu (2023)
	0.25 – 10		Saraswat, Digalwar, et al. (2021); Rezaian and Jozi (2016); Effat and El-Zeiny (2022); Nagababu, Puppala, et al. (2022)
	0.5 – 2		Baseer, Rehman, et al. (2017); Ali, Taweekun, et al. (2018); Moradi, Yousefi, et al. (2020); Noorollahi, Yousefi, et al. (2016); Amjad, Agyekum, et al. (2021); Raza, Yousif, et al. (2023); Yousefi, Moradi, et al. (2024)
Restited Distances	Minimum	< 0.25	Ayodele, Ogunjuyigbe, et al. (2018a); Tercan (2021); Moradi, Yousefi, et al. (2020); Noorollahi, Yousefi, et al. (2016); Ayodele, Ogunjuyigbe, et al. (2018b); Bina, Jalilinasrabady, et al. (2018); Albraheem, L., AlAwlaqi, L. (2023); Yegizaw and Mengistu (2023); Yildiz (2023); Yousefi, Moradi, et al. (2024); Bilgili, Arda, et al. (2024)
		< 0.5	Rezaian and Jozi (2016); Islam, Islam, et al. (2022); Amjad, Agyekum, et al. (2021); Dinçer, Demir, et al. (2023); Demir, Dinçer, et al. (2024)
	Maximum	> 5	Sanchez-Lozano, García-Cascales, et al. (2014); Pamučar, Gigović, et al. (2017); Benti, Alemu, et al. (2023); Yaman (2024)
		> 10	Baseer, Rehman, et al. (2017); Ali, Taweekun, et al. (2018); Moradi, Yousefi, et al. (2020); Rezaian and Jozi (2016); Amjad, Agyekum, et al. (2021)
		>20	Ayodele, Ogunjuyigbe, et al. (2018a); Gorsevski, Cathcart, et al. (2013); Islam, Islam, et al. (2022); Yegizaw and Mengistu (2023)
Range	<0.25; 0.25-2; 2-4; 4-6; 6-8; 8-10; >10		Moradi, Yousefi, et al. (2020); Noorollahi, Yousefi, et al. (2016); Yousefi, Moradi, et al. (2024)
	<0.25; 0.25-5; 5-10; 10-15; >15		Yegizaw and Mengistu (2023); Bilgili, Arda, et al. (2024)
	<0.25; 0.25-5; 5-10; 10-20		Ayodele, Ogunjuyigbe, et al. (2018a); Ayodele, Ogunjuyigbe, et al. (2018b)
	<0.5; 0.5-1; 1-2; 2-4; 4-8; 8-16; >16		Dinçer, Demir, et al. (2023); Demir, Dinçer, et al. (2024)
	<1; 1-2; 2-3; 3-4; 4-5; 5-6; 6-7; 7-8; 8-9		Cunden, Doorga, et al. (2020); Höfer, Sunak, et al. (2016)

Value (km)	Reference
<2; 2-5; 5-10; >10	Ali, Taweekun, et al. (2018); Amjad, Agyekum, et al. (2021)
<10; 10-20; 20-30; 30-40; >40	Saraswat, Digalwar, et al. (2021); Nagababu, Puppala, et al. (2022)

3.6.3 Proximity to transportation network

To minimize the construction costs, the proposed sites of wind farms should be located near the road network. Therefore, the nearer the distance from wind farm to main road is, the higher the advantage is. However, it should have a minimum restrictive distance to main roads because of visual impact, noise and safety of human, vehicles running on road and a maximum restricted distance to main roads due to equipment transportation. From the collected papers, the minimum distances were different among case studies, such as, 100m, 150m, 200m, 300m, 500m, 1.000m while the maximum distances were 1,000m, 2,000m, 3,000m, 5,000m, 10,000m, 15,000m, 20,000m, 40,000m. In contrast, the optimal distances were set as less than 100m, less than 500m, 500m-1,000m, 500m-2,000m, 500m-5,000m, less than 10,000m. Table 8 presented optimal distances, restrictive distances, and distance categories which used most in the selected papers.

Table 8. Distribution proximity to transport network for wind farm site selections

		Value (km)	Reference
Optimal distance		<0.1	Höfer, Sunak, et al. (2016); Konstantinos, Georgios, et al. (2019); Jangid, Bera, et al. (2016).
		<0.5	Sanchez-Lozano, García-Cascales, et al. (2014); Asadi, Pourhossein, et al. (2023); Yaman (2024).
		0.5 - 1	Yegizaw and Mengistu (2023); Rekik and Alimi (2023); Raza, Yousif, et al. (2023).
		0.5 - 2	Ali, Taweekun, et al. (2018); Moradi, Yousefi, et al. (2020); Noorollahi, Yousefi, et al. (2016); Amjad, Agyekum, et al. (2021); Yousefi, Moradi, et al. (2024).
		0.5 - 5	Ayodele, Ogunjuyigbe, et al. (2018a); Ayodele, Ogunjuyigbe, et al. (2018b); Islam, Islam, et al. (2022).
		<10	Saraswat, Digalwar, et al. (2021); Nagababu, Puppala, et al. (2022); Demir, Riaz, et al. (2024).
Excluded distance	Minimum	<0.1	Latinopoulos and Kechagia (2015); Tercan (2021); Bilgili, Arda, et al. (2024).
		<0.15	Gigović, Pamučar, et al. (2016); Pamučar, Gigović, et al. (2017); Aghaloo, Ali, et al. (2023).
		<0.5	Ayodele, Ogunjuyigbe, et al. (2018a); Moradi, Yousefi, et al. (2020); Noorollahi, Yousefi, et al. (2016); Cunden, Doorga, et al. (2020); Bina, Jalilinasrabady, et al. (2018); Al-Yahyai, Charabi, et al. (2012); Azizi, Malekmohammadi, et al. (2014); Gao, Wang, et al. (2022); Islam, Islam, et al. (2022); Amjad, Agyekum, et al. (2021); Albraheem, L., AlAwlaqi, L. (2023); Yegizaw and Mengistu (2023); Rekik and Alimi (2023); Raza, Yousif, et al. (2023); Yildiz (2023); Yousefi, Moradi, et al. (2024).
	Maximum	>5	Sanchez-Lozano, García-Cascales, et al. (2014); Benti, Alemu, et al. (2023); Yaman (2024).
		>10	Baseer, Rehman, et al. (2017); Ali, Taweekun, et al. (2018); Anwarzai and Nagasaka (2017); Gorsevski, Cathcart, et al. (2013); Effat and El-Zeiny (2022); Amjad, Agyekum, et al. (2021); Yegizaw and Mengistu (2023); Salih, Hassaballa, et al. (2024).
		>15	Ayodele, Ogunjuyigbe, et al. (2018a); Rekik and Alimi (2023); Abdi, Damci, et al. (2024).

	>40	Saraswat, Digalwar, et al. (2021); Nagababu, Puppala, et al. (2022); Demir, Riaz, et al. (2024).
Distance categories	<0.5; 0.5-2; 2-5; >5	Sanchez-Lozano, García-Cascales, et al. (2014); Ali, Taweekun, et al. (2018); Amjad, Agyekum, et al. (2021).
	<0.5; 0.5-2; 2-4; 4-6; 6-8; 6-10; >10	Moradi, Yousefi, et al. (2020); Noorollahi, Yousefi, et al. (2016); Yousefi, Moradi, et al. (2024).
	<10; 10-20; 20-30; 30-40; >40	Saraswat, Digalwar, et al. (2021); Nagababu, Puppala, et al. (2022); Demir, Riaz, et al. (2024).

3.6.4 Slope

The criterion on slope affects construction, equipment installation, and maintenance of wind farms. The deeper the slope is, the more difficult the construction is. From the literature, both "degree" and "percentage" units were used to indicate distribution of slope in the study areas. Most papers suggested optimal slope for wind farm site selection as less than 3 in percentage unit and less than 5 in degree unit. Moreover, restrictive value for slope were set as over 10, 15 in degrees and over 15, 20, 25, 30 in percentages. Table 9 summarized optimal and excluded values of slope as well as slope categories which were suggested in the literature.

Table 9. Distribution slope for wind farm site selections

	Value (degree/percentage)	Reference
Optimal slope	<5 degree	Tercan (2021); Pamučar, Gigović, et al. (2017). Ayodele, Ogunjuyigbe, et al. (2018a); Moradi, Yousefi, et al. (2020); Ayodele, Ogunjuyigbe, et al. (2018b); Höfer, Sunak, et al. (2016); Gao, Wang, et al. (2022); Islam, Islam, et al. (2022); Nagababu, Puppala, et al. (2022); Dinçer, Demir, et al. (2023); Albraheem and AlAwlaqi (2023); Yaman (2024); Demir, Dinçer, et al. (2024).
	<3%	Azizi, Malekmohammadi, et al. (2014); Asadi, Pourhossein, et al. (2023); Aghaloo, Ali, et al. (2023); Salih, Hassaballa, et al. (2024); Bilgili, Arda, et al. (2024).
	<5%	Tercan (2021); Konstantinos, Georgios, et al. (2019); Al-Yahyai, Charabi, et al. (2012); Tegou, Polatidis, et al. (2010); Jangid, Bera, et al. (2016); Rezaian and Jozi (2016); Josimovic, Srnic, et al.(2023).
	<10%	
Excluded slope	>10 degree	Cunden, Doorga, et al. (2020); Rekik and Alimi (2023).
	>15 degree	Saraswat, Digalwar, et al. (2021); Bina, Jalilinasrabady, et al. 2018); Demir, Riaz, et al. (2024). Ayodele, Ogunjuyigbe, et al. (2018a); Ali, Taweekun, et al. (2018); Ayodele, Ogunjuyigbe, et al. (2018b); Villacreses, Gaona, et al. (2017); Nagababu, Puppala, et al. (2022); Amjad, Agyekum, et al. (2021); Albraheem and AlAwlaqi (2023); Yaman (2024).
	>15%	Konstantinos, Georgios, et al. (2019); Koc, Turk, et al. (2019); Shorabeh, Firozjaei, et al. (2022); Salih, Hassaballa, et al. (2024).
	>20%	Tercan (2021); Tegou, Polatidis, et al. (2010); Josimovic, Srnic, et al.(2023); Bilgili, Arda, et al. (2024).
	>25%	Moradi, Yousefi, et al. (2020); Höfer, Sunak, et al. (2016); Azizi, Malekmohammadi, et al. (2014); Asadi, Pourhossein, et al. (2023); Yildiz (2023).
	>30%	
Range	<6; 6-9; 9-12; 12-15; >15 degree	Saraswat, Digalwar, et al. (2021); Demir, Riaz, et al. (2024).

	<3; 3-6; 6-10; 10-15; >15 %	Ayodele, Ogunjuyigbe, et al. (2018a); Ayodele, Ogunjuyigbe, et al. (2018b); Albraheem and AlAwlaqi (2023).
	<3; 3-6; 6-9; 9-12; 12-15; 15-18; 18-21; 21-37; 27-30; >30%	Moradi, Yousefi, et al. (2020); Höfer, Sunak, et al. (2016).
	<3; 3-6; 6-9; 9-12; 12-24; >24 %	Dinçer, Demir, et al. (2023); Demir, Dinçer, et al. (2024).
	<5; 5-10; 10-15; 15-20; 20-25; >25 %	Tercan (2021); Asadi, Pourhossein, et al. (2023); Salih, Hassaballa, et al. (2024); Bilgili, Arda, et al. (2024).
	<7; 7-12; 12-15; > 15 %	Ali, Taweekun, et al. (2018); Amjad, Agyekum, et al. (2021).

3.6.5 Proximity to settlement

A close proximity from wind farm site to residential areas causes noise, air pollution, visual impact during the construction of wind farm as well as operation period. Therefore, the further the distance is, the higher the advantage is. Moreover, restricted buffers were set to dismiss and avoid these impacts which were various according to case studies from the literature, such as 500m, 1,000m, 2,000m, 5,000m, 10,000m. In contrast, most papers pointed out that a distance of over 2,000m from the residential areas was considered as optimal distance for wind farm sitting. A statistic on values of optimal and restrictive distances and distance categories was presented in table 10 which were used most in literature.

Table 10. Distance from settlements for wind farm site selections

	Value (km)	**Reference**
Optimal distances	>2	Ali, Taweekun, et al. (2018); Anwarzai and Nagasaka (2017); Bina, Jalilinasrabady, et al. (2018); Al-Yahyai, Charabi, et al. (2012); Gao, Wang, et al. (2022); Shorabeh, Firozjaei, et al. (2022); Demir, Dinçer, et al. (2024).
	>5	Sanchez-Lozano, García-Cascales, et al. (2014); Pamučar, Gigović, et al. (2017); Aghaloo, Ali, et al. (2023).
	>20	Ayodele, Ogunjuyigbe, et al. (2018a); Ayodele, Ogunjuyigbe, et al. (2018b); Albraheem, L., AlAwlaqi, L. (2023); Yaman (2024).
	>40	Saraswat, Digalwar, et al. (2021); Nagababu, Puppala, et al. (2022); Demir, Riaz, et al. (2024).
Excluded distances	<0.5	Baseer, Rehman, et al. (2017); Gigović, Pamučar, et al. (2016); Ali, Taweekun, et al. (2018); Jangid, Bera, et al. (2016); Pamučar, Gigović, et al. (2017); Aghaloo, Ali, et al. (2023); Yildiz (2023).
	<1	Sanchez-Lozano, García-Cascales, et al. (2014); Tercan (2021); Rezaian and Jozi (2016); Amjad, Agyekum, et al. (2021); Demir, Dinçer, et al. (2024).
	<2	Ayodele, Ogunjuyigbe, et al. (2018a); Ayodele, Ogunjuyigbe, et al. (2018b); Anwarzai and Nagasaka (2017); Bina, Jalilinasrabady, et al. (2018); Al-Yahyai, Charabi, et al. (2012); Azizi, Malekmohammadi, et al. (2014); Gao, Wang, et al. (2022); Shorabeh, Firozjaei, et al. (2022); Albraheem, L., AlAwlaqi, L. (2023); Asadi, Pourhossein, et al. (2023); Rekik and Alimi (2023); Yaman (2024); Abdi, Damci, et al. (2024).
	<5	Islam, Islam, et al. (2022); Effat and El-Zeiny (2022); Raza, Yousif, et al. (2023).
	<10	Saraswat, Digalwar, et al. (2021); Nagababu, Puppala, et al. (2022); Demir, Riaz, et al. (2024).
Distance categories	<0.5; 0.5-1.5; >1.5	Jangid, Bera, et al. (2016); Pamučar, Gigović, et al. (2017).

<1; 1-2; >2	Rezaian and Jozi (2016); Demir, Dinçer, et al. (2024).
<5; 5-10; 10-20; 20-30; 30-50; >50	Islam, Islam, et al. (2022); Effat and El-Zeiny (2022); Raza, Yousif, et al. (2023).
<10; 10-20; 20-30; 30-40; >40	Saraswat, Digalwar, et al. (2021); Nagababu, Puppala, et al. (2022); Demir, Riaz, et al. (2024).

3.6.6 Land use

Land use was in top six criteria which was used in selected papers. This criterion indicates which types of land use are suitable or not suitable for wind farm sitting. From the literature, priority of land use type for wind farm site were various and different in case by case which included bare soil (bare land), range land (grass land), pasture, shrub or herbaceous vegetations, arable land, spare vegetation, In the contrast, land use types which consisted of urban areas (public settlement), water bodies, forest, wet land, irrigated agricultural land, artificial surface, were considered as prohibited and restricted areas for constructing wind farm. Table 11 showed potential and excluded types of land use which appeared mostly in the collected papers.

Table 11. Land use for wind farm site selection

	Type	Reference
Optimal land use	Bare soil (land)	Anwarzai and Nagasaka (2017); Potić, Joksimović, et al. (2021); Höfer, Sunak, et al. (2016); Azizi, Malekmohammadi, et al. (2014); Tegou, Polatidis, et al. (2010); Jangid, Bera, et al. (2016); Effat and El-Zeiny (2022); Nagababu, Puppala, et al. (2022); Dinçer, Demir, et al. (2023); Yegizaw and Mengistu (2023); Rekik and Alimi (2023); Raza, Yousif, et al. (2023); Aghaloo, Ali, et al. (2023); Yildiz (2023); Demir, Dinçer, et al. (2024); Abdi, Damci, et al. (2024).
	Range land / grass land	Ali, Taweekun, et al. (2018); Saraswat, Digalwar, et al. (2021); Anwarzai and Nagasaka (2017); Gorsevski, Cathcart, et al. (2013); Koc, Turk, et al. (2019); Amjad, Agyekum, et al. (2021); Dinçer, Demir, et al. (2023); Rekik and Alimi (2023); Raza, Yousif, et al. (2023); Aghaloo, Ali, et al. (2023); Yildiz (2023); Demir, Dinçer, et al. (2024).
	Pasture	Gigović, Pamučar, et al. (2016); Potić, Joksimović, et al. (2021); Gorsevski, Cathcart, et al. (2013); Pamučar, Gigović, et al. (2017); Yildiz (2023).
	Shrub or herbaceous vegetation	Latinopoulos and Kechagia (2015); Gigović, Pamučar, et al. (2016); Gorsevski, Cathcart, et al. (2013); Nagababu, Puppala, et al. (2022); Raza, Yousif, et al. (2023).
	Arable land	Gigović, Pamučar, et al. (2016); Potić, Joksimović, et al. (2021); Yildiz (2023).
	Spare vegetation	Rekik and Alimi (2023); Raza, Yousif, et al. (2023); Aghaloo, Ali, et al. (2023).
Excluded land use	Urban areas/ public settlement	Ali, Taweekun, et al. (2018); Tercan (2021); Potić, Joksimović, et al. (2021); Azizi, Malekmohammadi, et al. (2014); Tegou, Polatidis, et al. (2010); Pamučar, Gigović, et al. (2017); Effat and El-Zeiny (2022); Nagababu, Puppala, et al. (2022); Amjad, Agyekum, et al. (2021); Dinçer, Demir, et al. (2023); Yegizaw and Mengistu (2023); Rekik and Alimi (2023); Benti, Alemu, et al. (2023); Aghaloo, Ali, et al. (2023); Demir, Riaz, et al. (2024); Demir, Dinçer, et al. (2024); Abdi, Damci, et al. (2024).
	Water bodies	Gigović, Pamučar, et al. (2016); Gorsevski, Cathcart, et al. (2013); Azizi, Malekmohammadi, et al. (2014); Pamučar, Gigović, et al. (2017); Gao, Wang, et al. (2022); Effat and El-Zeiny (2022); Nagababu, Puppala, et al. (2022); Dinçer, Demir, et al. (2023); Yegizaw and Mengistu (2023); Rekik and Alimi (2023); Raza, Yousif, et al. (2023); Benti, Alemu, et al. (2023); Aghaloo, Ali, et al. (2023); Yildiz (2023); Demir, Riaz, et al. (2024); Demir, Dinçer, et al. (2024).
	Forest	Ayodele, Ogunjuyigbe, et al. (2018a); Saraswat, Digalwar, et al. (2021); Ayodele, Ogunjuyigbe, et al. (2018b); Potić, Joksimović,

Type	Reference
	et al. (2021); Höfer, Sunak, et al. (2016); Azizi, Malekmohammadi, et al. (2014); Tegou, Polatidis, et al. (2010); Jangid, Bera, et al. (2016); Pamučar, Gigović, et al. (2017); Gao, Wang, et al. (2022); Nagababu, Puppala, et al. (2022); Rekik and Alimi (2023); Raza, Yousif, et al. (2023).
Wet land	Latinopoulos and Kechagia (2015); Ayodele, Ogunjuyigbe, et al. (2018a); Gigović, Pamučar, et al. (2016); Ali, Taweekun, et al. (2018); Ayodele, Ogunjuyigbe, et al. (2018b); Gorsevski, Cathcart, et al. (2013); Nagababu, Puppala, et al. (2022); Amjad, Agyekum, et al. (2021); Yegizaw and Mengistu (2023); Yildiz (2023); Abdi, Damci, et al. (2024).
Irrigated agricultural land	Latinopoulos and Kechagia (2015); Azizi, Malekmohammadi, et al. (2014); Tegou, Polatidis, et al. (2010); Gao, Wang, et al. (2022); Effat and El-Zeiny (2022); Dinçer, Demir, et al. (2023); Josimovic, Srnic, et al.(2023); Raza, Yousif, et al. (2023); Aghaloo, Ali, et al. (2023); Yaman (2024); Demir, Dinçer, et al. (2024).
Artificial surface	Latinopoulos and Kechagia (2015); Gigović, Pamučar, et al. (2016); Tercan (2021); Yildiz (2023); Demir, Riaz, et al. (2024);

3.6.7 Elevation

Elevation is one of criteria which were used mostly for wind farm sitting from literature. The higher the elevation is, the higher the costs for construction and maintenance of wind farms are. Different case studies suggested different optimal elevations for wind farm sitting, such as less than 150m, 200m, 300m, 500m, 1,000m, 1,500m, 2,000m and different excluded elevations, such as, over 1,000m, 1,500m, 2,000m, 2,500m. *Table 12* summarized value of optimal and excluded elevation as well as elevation categories for wind farm site selection.

Table 12. Elevations for wind farm site selection

	Value (m)	Reference
Optimal elevation	<500	Ayodele, Ogunjuyigbe, et al. (2018a); Saraswat, Digalwar, et al. (2021); Nagababu, Puppala, et al. (2022); Yaman (2024); Demir, Riaz, et al. (2024).
	<2,000	Bina, Jalilinasrabady, et al. (2018); Rezaian and Jozi (2016); Shorabeh, Firozjaei, et al. (2022).
Excluded elevation	>1,000	Islam, Islam, et al. (2022); Raza, Yousif, et al. (2023).
	>1,500	Gao, Wang, et al. (2022); Bilgili, Arda, et al. (2024).
	>2,000	Ayodele, Ogunjuyigbe, et al. (2018a); Saraswat, Digalwar, et al. (2021); Moradi, Yousefi, et al. (2020); Ayodele, Ogunjuyigbe, et al. (2018b); Bina, Jalilinasrabady, et al. (2018); Rezaian and Jozi (2016); Shorabeh, Firozjaei, et al. (2022); Nagababu, Puppala, et al. (2022); Aghaloo, Ali, et al. (2023); Yaman (2024); Demir, Riaz, et al. (2024).
Elevation categories	<200; 200-500; 500-1,000; 1,000-2,000; >2,000	Ayodele, Ogunjuyigbe, et al. (2018a).
	<250; 250-500; 500-750; 750-1,000; 1,000-1,250	Islam, Islam, et al. (2022).
	<500; 500-1,000; 1,000-1,500; 1,500-2,000; >2,000	Saraswat, Digalwar, et al. (2021); Nagababu, Puppala, et al. (2022); Yaman (2024); Demir, Riaz, et al. (2024).

3.6.8 Proximity to nature and protected areas

The nature and protected areas consist of forests, wetland, wildlife designations, bird areas, Natura 200 areas, conservation zones, natural environment, and protected areas which must be protected from damage to nature and diverse species of flora and fauna, animal habitat. Therefore, a restrictive distance from these areas were set which were varied in case by case, such as less than 500m, less than 1,000, less than 2,000m. The further the distance is, the higher the advantage is. Moreover, in some selected papers, this criterion was considered as a constraint criterion which means that a buffer zone of a restrictive distance will be excluded from wind farm sitting. Besides that, some studies suggested an optimal distance from wind farm sites as 2km, 5km, 4km. A statistic on value of optimal and restrictive distances as well as distance categories on from naturae and protected areas to wind farm sites was presented in *Table 13*.

Table 13. Distance from nature and protect area for wind farm site selections

	Value (km)	Reference
Optimal distances	2	Bina, Jalilinasrabady, et al. (2018); Shorabeh, Firozjaei, et al. (2022)
	5	Gigović, Pamučar, et al. (2016); Tercan (2021); Nagababu, Puppala, et al. (2022); Josimovic, Srnic, et al. (2023); Yaman (2024); Demir, Riaz, et al. (2024)
	40	Saraswat, Digalwar, et al. (2021); Bilgili, Arda, et al. (2024)
Excluded distances	<0.5	Ayodele, Ogunjuyigbe, et al. (2018a); Ayodele, Ogunjuyigbe, et al. (2018b); Yaman (2024)
	<1	Tercan (2021); Asadi, Pourhossein, et al. (2023); Josimovic, Srnic, et al.(2023); Bilgili, Arda, et al. (2024)
	<2	Gigović, Pamučar, et al. (2016); Moradi, Yousefi, et al. (2020); Noorollahi, Yousefi, et al. (2016); Bina, Jalilinasrabady, et al. (2018); Azizi, Malekmohammadi, et al. (2014); Shorabeh, Firozjaei, et al. (2022)
Distance categories	<0.5; 0.5-1; 1-2.5; 2.5-5; >5	Yaman (2024)
	<1; 1-3; 3-5; 5-; >7	Tercan (2021)
	<2; 2-4; 4-5; 5-6; >6	Azizi, Malekmohammadi, et al. (2014)
	<2.5; 2.5-5; >5	Rezaian and Jozi (2016)

3.6.9 Proximity to airports

The height of wind turbines, which are about 80m to 150m from the land surface, interferes with airplanes taking off and landing. Moreover, wind turbines can also affect radio signals and telecommunication networks, and they can make distractions to the pilot's vision which result in losing aviation safety. Because of these problems, proposed wind farm sites should be far from airports, and a restrictive distance should be set. The further the distance is, the higher the advantage is. From the literature, the restrictive distances were varied among case studies, such as less than 2.5km, 3km, 5km, 7km while some studies suggested optimal distances as over 4km, 28km. *Table 14* represented values of restrictive, optimal distances and distance categories which were used mostly in literature.

Table 14. Distances from airport for wind farm site selection

	Value (km)	Reference

Optimal distances	>4	Ali, Taweekun, et al. (2018); Amjad, Agyekum, et al. (2021); Yegizaw and Mengistu (2023)
	>28	Saraswat, Digalwar, et al. (2021); Demir, Riaz, et al. (2024)
Excluded distances	<2.5	Baseer, Rehman, et al. (2017); Moradi, Yousefi, et al. (2020); Noorollahi, Yousefi, et al. (2016); Villacreses, Gaona, et al. (2017); Bina, Jalilinasrabady, et al. (2018)
	<3	Gigović, Pamučar, et al. (2016); Ali, Taweekun, et al. (2018); Tercan (2021); Azizi, Malekmohammadi, et al. (2014); Islam, Islam, et al. (2022); Amjad, Agyekum, et al. (2021); Yaman (2024); Bilgili, Arda, et al. (2024)
	<5	Ayodele, Ogunjuyigbe, et al. (2018a); Ayodele, Ogunjuyigbe, et al. (2018b); Nagababu, Puppala, et al. (2022); Albraheem and AlAwlaqi (2023);
	<7	Sanchez-Lozano, García-Cascales, et al. (2014); Saraswat, Digalwar, et al. (2021); Demir, Riaz, et al. (2024)
Distance categories	<3; 3-3.5; 3.5-4; >4	Ali, Taweekun, et al. (2018); Amjad, Agyekum, et al. (2021)
	<3; 3-5; 5-7; 7-10; >10	Tercan (2021); Yaman (2024)
	<7; 7-14; 14-21; 21-28; >28	Saraswat, Digalwar, et al. (2021); Demir, Riaz, et al. (2024)

3.6.10 Proximity to water bodies

Water bodies include rivers, reservoirs, dams, lakes, ponds have significant value of ecology which should be prevented from constructing wind farms. Moreover, flooding may also occur from the rivers and wind power farms may pollute the water bodies. Therefore, the further the distance from water bodies to wind farms is, the higher the advantage for constructing wind farms is, and a restricted distance should be set. Among collected papers, distances of less than 200m, 500m, 1,000m were suggested mostly as excluded distances while the optimal distances for constructing wind farms were set as over 200m, 500m, 1,000m. *Table 15* presented a list of optimal and restrictive distances and distance categories which were suggested mostly in literature.

Table 15. Distances from water bodies for wind farm site selections

	Value (km)	**Reference**
Optimal distances	>0.2	Ayodele, Ogunjuyigbe, et al. (2018a); Albraheem and AlAwlaqi (2023); Yegizaw and Mengistu (2023)
	>0.5	Bina, Jalilinasrabady, et al. (2018); Gao, Wang, et al. (2022)
	>1	Azizi, Malekmohammadi, et al. (2014); Shorabeh, Firozjaei, et al. (2022); Nagababu, Puppala, et al. (2022)
Restricted distances	<0.2	Ayodele, Ogunjuyigbe, et al. (2018a); Ayodele, Ogunjuyigbe, et al. (2018b); Albraheem and AlAwlaqi (2023); Yegizaw and Mengistu (2023); Benti, Alemu, et al. (2023)
	<0.5	Bina, Jalilinasrabady, et al. (2018); Gao, Wang, et al. (2022); Josimovic, Srnic, et al.(2023); Aghaloo, Ali, et al. (2023); Demir, Riaz, et al. (2024); Bilgili, Arda, et al. (2024)
	<1	Moradi, Yousefi, et al. (2020); Noorollahi, Yousefi, et al. (2016); Shorabeh, Firozjaei, et al. (2022); Nagababu, Puppala, et al. (2022)
Distance categories	<0.5; 0.5-1; 1-5; 5-15; >15	Aghaloo, Ali, et al. (2023)
	<0.5; 0.5-2; 2-4; 4-6; >6	Demir, Riaz, et al. (2024)

	<0.5; 0.5-2.5-5; 5-7.5; 7.5-10; >10	Bilgili, Arda, et al. (2024)

3.7 Combinations of criteria

Apart from determining importance order of top ten criteria, identifying combinations of criteria is also considered as another new finding in this research which indicates criteria appeared together for wind farm sitting. This will support local government, planners, investors, and researchers selecting necessary criteria for wind farm siting. Based on the results on top ten criteria which were employed most in the collected publications, this study also suggested a method for calculating frequency of combinations of criteria appeared in the collected publications as follows.

First of all, the top ten criteria include C1-Wind speed; C2- Distance from transmission lines; C3-Distance from road network; C4- Slope; C5-Distance from settlements; C6-Land use; C7- Elevation; C8- Distance from nature area and nature protect area; C9- Distance from airport; C10- Distance from water bodies. Binary values with 0 and 1 were applied to indicate whether a criterion appeared in each publication (1 for appearance and 0 for non-appearance). This step was proceeded with Excel.

In second step, combinations of 2,3,4,5,6,7,8,9,10 criteria were determined. The binary values with 0 and 1 were also employed to indicate whether all criteria of each combination appeared in each publication. C1C2, for instance, is one of combinations of 2 criteria, value of C1C2 at each publication is 1 if C1 and C2 appear simultaneously in the same publication while value of C1C2 is 0 if neither C1 and C2 or only C1 or C2 appear in the same publication. Numbers of each combination C were calculated based on following *Equation 2*.

$$C_{10}^{k} = 10!/k!\,(10-k)! \quad (k \in [2;10]) \tag{2}$$

As a result, the top 106 combinations with highest frequency among 107 combinations were presented in *Table 16*. According to statistic results, a combination of two criteria including "wind speed (C1) and distance from road network (C3)" appeared the most with a frequency of 50 times (maximum is 58 times). The next two combinations were "distance from road network (C3) and slope (C4)" and "wind speed (C1) and slope (C4)" with frequencies of 47 times and 44 times respectively. The result also showed frequencies of combinations of three, four, five and six criteria which were 42, 34, 28, 16 times respectively.

Table 16. Combination of criteria

No.	Combinations of criteria	Frequency	No.	Combinations of criteria	Frequency
1	C1C3	50	55	C1C8	17
2	C3C4	47	56	C4C7	17
3	C1C4	44	57	C4C8	17
4	C1C2	43	58	C5C8	17
5	C2C3	43	59	C2C3C5C6	17
6	C3C5	43	60	C2C4C5C6	17
7	C1C3C4	42	61	C1C2C3C5C6	17
8	C1C2C3	41	62	C1C2C4C5C6	17
9	C1C5	39	63	C2C8	16
10	C4C5	39	64	C1C3C7	16
11	C2C4	38	65	C1C3C8	16
12	C1C3C5	38	66	C1C4C7	16
13	C3C4C5	38	67	C3C4C8	16

No.	Combinations of criteria	Frequency	No.	Combinations of criteria	Frequency
14	C1C2C4	36	68	C3C5C8	16
15	C2C3C4	36	69	C2C3C4C5C6	16
16	C1C4C5	35	70	C1C2C3C4C5C6	16
17	C2C5	34	71	C2C3C8	15
18	C1C2C3C4	34	72	C3C4C7	15
19	C1C3C4C5	34	73	C4C5C8	15
20	C1C6	33	74	C2C7	14
21	C3C6	33	75	C5C7	14
22	C4C6	33	76	C1C2C7	14
23	C2C3C5	33	77	C1C2C8	14
24	C1C2C5	32	78	C1C4C8	14
25	C1C3C6	31	79	C1C5C8	14
26	C1C4C6	31	80	C2C5C8	14
27	C2C4C5	31	81	C1C3C4C7	14
28	C3C4C6	31	82	C3C4C5C8	14
29	C1C2C3C5	31	83	C6C7	13
30	C2C3C4C5	30	84	C6C8	13
31	C1C2C4C5	29	85	C1C5C7	13
32	C1C3C4C6	29	86	C1C6C7	13
33	C1C2C3C4C5	28	87	C2C4C8	13
34	C5C6	26	88	C3C5C7	13
35	C2C6	25	89	C1C2C3C8	13
36	C1C2C6	25	90	C1C3C4C8	13
37	C3C5C6	25	91	C1C3C5C8	13
38	C4C5C6	25	92	C2C3C5C8	13
39	C1C5C6	24	93	C1C9	12
40	C3C4C5C6	24	94	C3C10	12
41	C2C3C6	23	95	C1C6C8	12
42	C2C4C6	23	96	C2C3C7	12
43	C1C2C3C6	23	97	C2C4C7	12
44	C1C2C4C6	23	98	C3C6C8	12
45	C1C3C5C6	23	99	C4C6C7	12
46	C1C4C5C6	23	100	C1C2C3C7	12
47	C1C3C4C5C6	22	101	C1C2C4C7	12
48	C2C3C4C6	21	102	C1C2C5C8	12
49	C1C2C3C4C6	21	103	C1C3C5C7	12
50	C3C8	19	104	C1C4C5C8	12
51	C1C7	18	105	C1C4C6C7	12
52	C3C7	18	106	C2C3C4C8	12
53	C2C5C6	18	107	C2C4C5C8	12
54	C1C2C5C6	18			

As the result, the integration of GIS and AHP was the most popular method for wind farm siting from collected papers which were also studied by Rediske, Burin, et al. (2021), Joshua, Chinedu et al. (2023). Furthermore, Rediske, Burin, et al. (2021) described 30 criteria in detail which were classified to 6 categories while Joshua, Chinedu et al. (2023) presented top 15 used criteria compared with 64 criteria in this study. Among criteria, this study showed that distance from road network, wind speed, slope, distance from transmission lines, distance from residential area, land use were in top six criteria used the most (also presented by Rediske, Burin, et al. (2021)) while distance from natural and protected area, elevation, distance from surface water, distance from airports were in top ten criteria used the most (also presented by Joshua, Chinedu et al. (2023)).

Moreover, as mentioned in the “introduction” section, this research contributed a detailed description of top ten criteria with following information: importance order, value categories, potential value, restrictive values which have not conducted by Rediske, Burin, et al. (2021), Joshua, Chinedu et al. (2023), Tsani, Michael, et al. (2024). Moreover, one more new contribution of this study was determining the combinations of criteria which simultaneously appeared most in the papers.

Therefore, based on the results of importance order, value categories, potential value, restrictive values, and combinations of criteria, local government, planners, investors may easily consider and select criteria, as well as determine value categories of selected criteria.

4. CONCLUSION

This study conducted the literature review on wind farm sitting and pointed out two new contributions from the previous systematic review research which included the detailed description of top ten criteria with following information: importance order, value categories, potential value, restrictive values and proposing combinations of criteria. The analytic results on method and software indicated that integration between AHP and GIS (ArcGIS software) was the most popular method for location choice model. Moreover, among used criteria, "distance from road network" was preferred the most with a frequency of 52 (per 58 times) while "wind speed" was considered as the most important criterion. Furthermore, the importance (weight) order of top ten most used criteria was calculated which was wind speed, distance from transmission lines, distance from road network, slope, distance from settlement, land use, elevation, distance from natural and protected area, distance from airports, distance from water bodies. Finally, among criteria combinations, the combination of two criteria "wind speed - C1" and "distance from road network - C3" was used the most with a frequency of 52 (in total of 58 times) while combinations of 3 (C1C3C4), 4 (C1C2C3C4), 5 (C1C2C3C4C5), 6 (C1C2C3C4C5C6) different criteria had frequencies of 42, 34, 28, 16 times respectively.

As the results, the research also contributed a set of useful and necessary information for making decisions on suitable wind farm site selection which may help researchers, local government, investors easily determine and choose relevant influenced criteria and suitable methods. However, a limitation of this research was not stratifying criterion importance and threshold ranges by region (climate zone), study scale, and turbine hub height. This classification may be considered for further research in future.

Furthermore, this study is a first step of our future research on "GIS-based model for suitable wind farm site selection in the South-Central Vietnam".

AUTHOR CONTRIBUTIONS

Conceptualization, D-T.N, and M-H.T.; methodology, T-M-T.N., and Y.Y; investigation, T-T.N., T-A-L.N. and N-H.N; data curation, D-T.N, T-M-T.N., T-T.N., T-A-L.N. and N-H.N; writing—original draft preparation, D-T.N, M-H.T, Y.Y and T-M-T.N.; writing—review and editing, D-T.N, M-H.T, Y.Y and T-M-T.N.; supervision, M-H.T and Y.Y. All authors have read and agreed to the published version of the manuscript.

ETHICS DECLARATION

The authors declare that they have no conflicts of interest regarding the publication of the paper.

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