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A Literature Review: Wind Energy Within The Scope of MCDM Methods

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Highlights

- Literature review of wind energy studies within the scope of multi-criteria decision making methods.
- Evaluation of published studies according to publisher organizations and countries.
- Evaluation within the scope of abstracts and keywords of published studies.

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Abstract

Renewable energy sources (RES) are vital for environmental sustainability. With the depletion and damage of fossil fuels to nature, energy production from clean and inexhaustible RES has become widespread. Wind energy, one of the RES, is a clean energy source that does not emit any harmful waste to the environment. Wind energy is a low-cost energy source that is mostly used for electricity generation. Criteria such as wind speed, turbine structure and the characteristics of the areas where the wind turbines will be located are effective on the amount of energy to be produced. In this study, a comprehensive review of the studies using MCDM methods related to wind energy is made. In the manner of the statistical data obtained from the 97 studies examined, it has been observed that the wind energy investments and the scientific publications made in these countries do not progress linearly with each other. The fact that countries have different wind energy potentials and the difference in the countries' interest in RES is thought to be effective in this regard. While there are articles in the literature in which studies on RES are discussed together with MCDM methods, there is no comprehensive review study in which wind energy and MCDM methods are discussed together. According to our best knowledge, this is the first study to comprehensively evaluate wind energy studies in terms of MCDM methods. With this study, a framework has been presented for subsequent studies on the application of MCDM methods in wind energy.

1. INTRODUCTION

Energy, which can be defined in the most general sense, is the ability to do work. Energy is a resource needed for all kinds of production and even consumption. People have benefited from different materials such as wood, human and animal power, rivers, coal, oil, natural gas, nuclear energy, hydrogen and boron as energy sources over time. However, it is also known that humanity continues to seek to produce energy from different materials under economic conditions, due to environmental reasons and limited availability, depending on the science and technology possibilities of the day.

Energy resources are classified according to various criteria. These criteria can be changed by understanding of renewability/non-renewability or exhaustibility/non-exhaustibility respectively in time and location scope, primary/secondary source form, energy technology or homogeneity of a source (various combination of characteristics) [1]. In this context; energy resources can be classified as primary resources, suitable for end use without any conversion to another form (wind power, solar power, wood, fossil fuels such as coal, oil and natural gas, uranium), or secondary resources, where the energy required conversion from a primary source (electricity, hydrogen, or other synthetic fuels). Another energy resources classification may be renewable and non-renewable form. Renewable energy is described as an energy source which can be exactly present the next day in nature's own evolution [2]. These are wind, solar, bio-

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mass, wave, geothermal, hydro. Non-renewable energy source such as coal, oil, natural gas will eventually run out one day.

According to dependence on the energy issue, decrease in fossil-based fuel production and environmental imperatives motivate many countries to establish long-term policies to deal with energy demands. It is estimated that petroleum will be consumed in nearly 51 years, coal in 114 years, and natural gas in 53 years, and these periods will change depending on the usage [3].

According to the International Energy Agency (IEA); although global energy demand decreased by 4 % in 2020 due to the pandemic, according to the first quarter data of 2021, as the Covid restrictions are ended and economies recover, energy demand is expected to increase by 4.6% and in 2021, global energy use is expected to be 0.5% above the pre-Covid-19 level [4]. "2021 World Oil Outlook" report, which includes the medium and long-term forecasts of the Organization of Petroleum Exporting Countries (OPEC) on the global economy, energy and oil demand will reach 352 million barrels of oil equivalent per day in 2045. As of 2020, energy production by source is presented in Figure 1. When examined, it is seen that energy production from fossil-based sources, which will be consumed soon, is at a high rate [4]. Especially when environmental effects such as carbon emissions are evaluated, humanity should want to use resources that are not likely to be exhausted and are generous in nature.

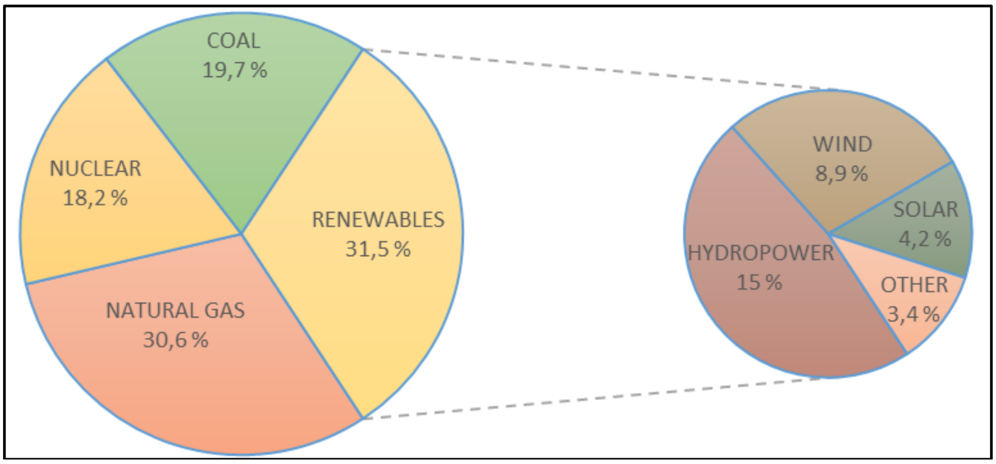

Figure 1. *Energy production by source*

The need for energy is generally eliminated from fossil-based resources, however the way of meeting the energy demand problem changed by adopting sustainable and renewable energy sources. In addition to industry, non-manufacturing public institutions have also increased their energy needs. The cost of energy required by public institutions has a considerable portion in the budget of countries. The decrease in fossil-based energy sources, the increase in costs, environmental concern, and the need for sustainable energy have caused countries to invest in renewable energy sources such as solar/wind energy. And also countries developed their technologies to improve efficiency or energy storage systems.

Existing renewable energy sources are summarily defined as follows. Solar energy is the radiation energy released by the fusion process in the core of the sun (Conversion of hydrogen gas to helium); Wind energy is the type of energy obtained by converting the kinetic energy of the wind into mechanical energy first and then into electricity; Geothermal energy is heat, which comes from Earth's core, generated during the original formation of the planet; Hydro energy is a type of energy obtained by various methods (dam, embankment) according to the flow and fall rate of the flowing water; Biomass energy is a type of energy which obtained by thermochemical and biochemical processing of organic materials [5].

Since the main theme of this study is wind energy, the information on wind energy has been expanded more. Wind energy; is a natural, renewable, clean and endless power and its source is the sun. A small amount of the energy (1-2 %) which sent to the world by the sun is transformed into wind energy. As a result of the sun's inability to heat the earth's surface and atmosphere homogeneously, airflow occurs temperature and pressure difference. If air mass gets hotter, it rises above the atmosphere and the same volume of cold air mass settles in the emptied place. The displacement of these air masses is called wind. In other words, the wind is the air flow that occurs due to the pressure differences between two adjacent pressure regions and moves from the high pressure center to the low pressure center. As the winds flow from high pressure areas to low-pressure areas; it takes form from the Earth's rotation around its own axis, surface frictions, local heat distribution, different atmospheric events and the topographic structure of the land. The characteristics of the wind show temporal and regional variation due to local geographical differences and inhomogeneous warming of the earth [6].

While investing in a wind power plant, first of all, the wind capacity of the region should be measured. With these calculations, the propeller length, blade system and turbine model can be decided. If the materials are not optimized according to the capacity of the wind, deterioration of the propellers is a normal result and the efficiency will decrease. The position of the wind turbine is also important to affect the ecosystem. For this reason, care should be taken when deciding the place can cause serious damage to the ecosystem such as migration routes of birds. The analysis of the region must be examined well, then the design, material needs and impact on the ecosystem should be met according to the requirements of the region [7]. Wind farms are built not only on land but also above sea, depending on the depth (on shore and off shore wind farms). And also some of the wind farms such as Hywind Wind Farm can float at the sea. In addition to the disadvantages of wind energy applications such as high initial investment cost, low capacity factors, and variable energy production, it has advantages such as being abundant and free in the atmosphere, no risk of depletion and increase in price over time, low maintenance and operating costs [8].

According to the Global Wind Energy Council 2021 Report, 2020 was the best year in history for the global wind industry with 93 GW of new capacity installation and helping to avoid over 1.1 billion tons of CO_2 globally with the 742.689 GW (707.396 MW on shore, 35.196 MW off shore) of wind power capacity worldwide [9].

Off shore and on shore wind farm investments from 2001 to 2020 are presented in Figure 2. When Figure 2 is examined, it is observed that this type of renewable energy power plant investment increases gradually, although it seems to decrease in some years. In Figure 3, wind energy investments by country will be seen. It is observed that countries with high energy needs generally invest in such a power plant, on shore and off shore investments vary according to their geographical characteristics [10].

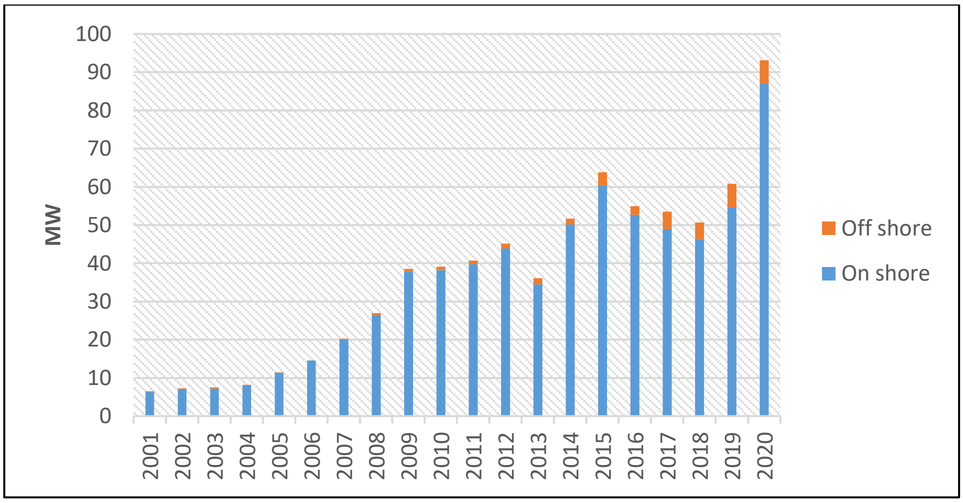

Figure 2. *Wind farm development*

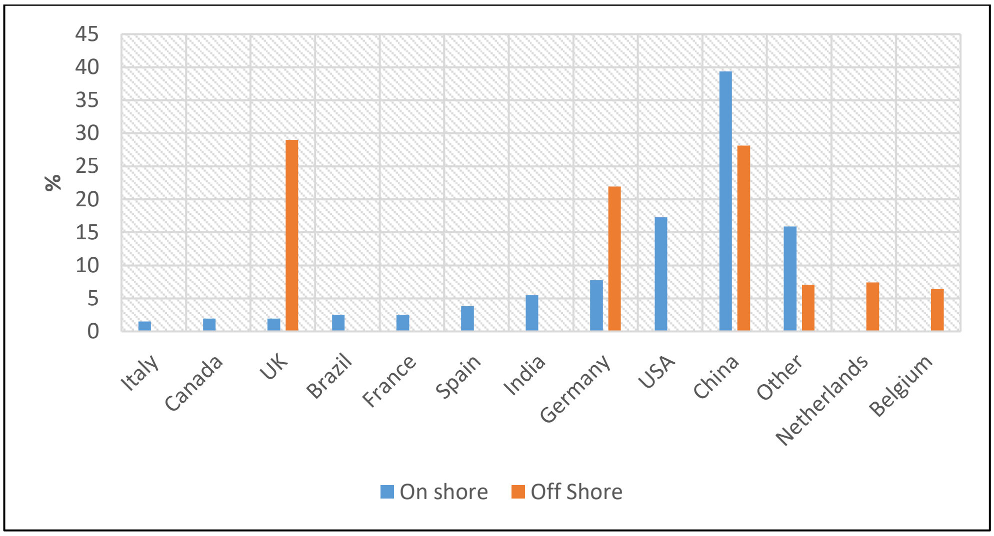

Figure 3. *Wind farm distribution*

Considering the energy needs, many countries have made investments to meet the demand and the fact that there is an end for the fossil-based fuels and environmental reasons, renewable energy sources come to the fore and many studies have been carried out in this regard. In addition to investment, existence and potential of energy resources studies, many studies were carried out on the selection of energy sources. Instead of technical/feasibility studies, multi-criteria decision making (MCDM) methods were used to provide a preliminary idea to the investors or decision makers.

MCDM methods are stated as the solution of problems in which multiple and conflicting goals (criteria) are desired to be achieved. In order to solve a problem with one of the MCDM methods, there must be a set of alternatives, criteria and decision makers. There are many methods in the literature. Some of these are Analytical Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), ÉLimination et Choix Traduisant la Realité (Elimination Et Choice Translating Reality, ELECTRE), Stepwise Weight Assessment Ratio Analysis (SWARA), Decision Making Trial and Evaluation Laboratory (DEMATEL), Measuring Attractiveness by a Categorical-Based Evaluation Technique (MACBETH), Multi-Attributive Border Approximation Area Comparison (MABAC), Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Stochastic multicriteria acceptability analysis (SMAA) etc. Some of the methods are extended by using fuzzy numbers such as Fuzzy AHP, Fuzzy DEMATEL, Fuzzy SWARA etc., also hybrid models were created by using them together such as DEMATEL+SMAA-2, SWARA+TOPSIS etc.

Due to the importance of selecting a renewable energy source or determining the facility/location for the selected renewable energy or determining the materials to be used or activities related to it renewable energy farm investment, many studies exist in the literature. In this study, a literature review was conducted related to MCDM methods which regards to one of the renewable energy sources: wind energy. The main purposes of this study are gathering the studies in the literature in one source and to present a short summary for the readers/users and more importantly, to contribute to new studies by identifying the areas/methods that have not been studied before. This study’s novelty is the first study limited to MCDM methods related to wind energy. The rest of the paper is organized as follows: In the second section, the research methodology and findings are included. Finally, the third section contains the conclusion and suggestions for future works.

2. REVIEW METHODOLOGY AND RESULTS

This study is structured, including the scientific publications of both the keywords "Multi-criteria decision making" and "Wind energy" between the years 2004-2022. The publications are selected from the studies in which the words are included both in the abstract and in the keywords. In this context, Ebsco, ScienceDirect, Tandofline, Springer, and Wiley databases were searched, as well as the "Google Scholar" search engine. 103 of the 132 publications are included in the study. 29 were excluded from the scope due to the lack of study subject and information. Brief information on the objectives of the publications reviewed is given in Table 1.

Table 1. *Summary information of the reviewed publications with respect to objectives*

Reference Number	Objective
[11]	To decide the location of the wind observatory to be established on the university campus based on the AHP
[12]	Wind farm site selection in Lesvos Island using AHP GIS hybrid method
[13]	To demonstrate different factors such as social acceptance and environmental factors that influence the suitability of wind farm areas
[14]	Site selection for a wind power plant using integrated GIS-MCDM approach in continental Ecuador
[15]	To determine the most appropriate support structures for offshore wind turbines
[16]	Application of offshore wind power site selection in Intuitionistic fuzzy environment
[17]	To obtain land suitability index using GIS-based AHP-OWA integrated method
[18]	Application of onshore wind farm location selection using integrated fuzzy approach
[19]	To evaluate alternative sites of offshore wind farms using newly developed fuzzy integrated MCDM technique
[20]	To cope with uncertainties in the wind energy technology selection process using the proposed interval-valued intuitionistic fuzzy method
[21]	To use Type 2 Fuzzy AHP and GIS-based model that concentrates on uncertainties arising from linguistic expressions of decision-makers in the wind farm installation process
[22]	To present the most suitable marine areas for establishing wind and wave energy systems using the MCDM-GIS integrated method
[23]	To explore site suitability for wind farm installation using combined AHP-GIS approach
[24]	To determine the ideal areas for solar-wind farms using GIS-based MCDM approach in Thailand
[25]	To recommend a new framework for modeling and identifying appropriate sites for offshore wind farms
[26]	Determination of suitable areas for wind turbines offshore the Baltic Sea and evaluation of wind turbines types
[27]	To evaluate alternative wind turbines performance in Taiwan
[28]	To present a framework considering criteria that include security, cost, capacity and demonstrate MCDM based assessment for offshore wind plant areas using real-world data
[29]	To ensure sustainability assessment of offshore wind farm siting using the proposed (PROSA) method
[30]	To develop hybrid interval type 2 fuzzy MCDM method for risk-based wind energy investment analysis
[31]	To determine the suitable location of the wind farm in a fuzzy environment
[32]	To evaluate the performance of wind turbines using the newly proposed fuzzy TOPSIS method
[33]	To investigate the most suitable location of offshore wind farms in Greece
[34]	Application of the newly proposed hybrid MCDM method to determine appropriate locations for offshore wind energy plants using neutrosophic numbers
[35]	Wind farm location selection using COPRAS-F method in fuzzy environment
[36]	To introduce a hybrid method for wind turbine technology transfer strategies
[37]	To suggest the most appropriate strategy for a hybrid wind farm
[38]	To show a framework for evaluating the sustainability of wind turbine tower alternatives using multi-criteria analysis
[39]	To analyze the most favorable offshore wind farms in Ireland using interval type 2 fuzzy numbers with MCDM methods for sustainable development.
[40]	Assessment of risk factors for distributed wind power investment

[41]	To utilize the GIS-MCDM integrated method for selecting wind plant location and energy resource analysis
[42]	Selection of most suitable support structures for offshore wind turbines
[43]	Selection of suitable wind turbine for wind energy station
[44]	Assessment of wind turbines using proposed two level selection method
[45]	Evaluation of the offshore wind turbine support structure alternatives using TOPSIS
[46]	Determination of suitable sites for solar-wind farm installation using GIS and optimum site selection with AHP
[47]	To suggest a novel GIS-based integrated Interval AHP-Stochastic VIKOR method for determining the most suitable sites for wind farms
[48]	To point out the criteria affecting the wind turbine selection and supply AHP based evaluation model
[49]	Determination of suitable material for wind turbine blade applying AHP-TOPSIS combined approach
[50]	To investigate favorable provinces for wind energy power plants to generate hydrogen
[51]	To investigate the suitability of areas for alternative wind turbines in Jordan
[52]	To evaluate the suitability of potential wind farm areas using the MCDM-GIS-based method
[53]	To determine the most appropriate areas for wind farm installation in Takestan
[54]	Investigation of the feasibility of a new tree-shaped wind turbine for urban regions in Iran with DEA and Fuzzy TOPSIS integrated approach
[55]	Suggestion of the optimum site for the offshore wind farm installation
[56]	To point out the most suitable areas for wind turbines siting applying MCDM-GIS integrated decision-making model
[57]	To select the optimum strategy in case of deficit power for a hybrid wind farm operation using MCDM methods
[58]	To investigate the social acceptance of wind energy using an optimized MCDM approach
[59]	Evaluation of wind energy production and hydrogen production potential from technical, economic, and environmental aspects with the hybrid SWARA-EDAS method
[60]	To develop a fuzzy integrated MCDM method for location selection of wind farms
[61]	To identify the most suitable wind turbines using MCDM methods combined with single-valued neutrosophic numbers
[62]	Evaluating alternative wind turbines considers technical, economic, environmental, and customer-related criteria
[63]	To identify the criteria affecting offshore wind energy and demonstrate significant criteria
[64]	To develop a GIS-MCDM combined method for bottom-fixed offshore wind energy power plants
[65]	To present qualitative and quantitative decision-making framework for wind power plant site selection
[66]	To develop a fuzzy MCDM approach for the wind turbine supplier evaluation
[67]	To develop fuzzy logic-based MCDM approach for the wind farm design process
[68]	To develop the hybrid MARCOS method with rough interval numbers for deciding the offshore wind farm site in a coastal region of Turkey
[69]	To decide the most suitable location of a wind plant in the Marmara Region
[70]	To demonstrate an innovative framework for wind farm siting using combined GIS-Fuzzy MCDM methods
[71]	To explore applicable sites for offshore wind farms using intuitionistic fuzzy MCDM approach in the Black Sea region
[72]	To determine the most suitable location for the wind farm that consists of 14 turbines using different MCDM methods
[73]	To suggest fuzzy goal programming based MCDM method for wind turbine selection
[74]	Application of a deterministic, stochastic, and hybrid MCDM approach for wind power plant siting

[75]	Assessment of offshore wind farm investments in Poland with fuzzy TOPSIS method and revealing the most sustainable investments
[76]	Selection of the most appropriate city to install wind farms
[77]	To introduce innovative grey decision-making approach (DANP) and grey relational analysis for offshore wind power plant location selection process
[78]	To present sustainability evaluation of wind energy projects with an integrated MCDM approach
[79]	To determine appropriate wind turbines for offshore wind farms
[80]	To evaluate the potential of wind energy and hydrogen production by making technical, economical, carbon footprint assessments in Afghanistan and identifying the best places to produce hydrogen from wind energy with combined SWARA-EDAS MCDM methods
[81]	To identify the human-free lifting process in establishing offshore wind farms using the stochastic TOPSIS approach
[82]	To recommend optimum wind turbines for wind farm areas
[83]	Application of density-based clustering and MCDM methods in the determination, optimization, and sequencing of candidate sites in site selection for wind farms in Ghana
[84]	Analysis of the proper locations for the development of wind energy resources
[85]	To use GIS-based fuzzy MCDM approach for determining the most suitable areas for wind farms
[86]	To identify the wind turbine type that is the best compatibility with the wind farm site's characteristics where the turbines will be installed
[87]	To identify the optimum site for wind energy plant using two stages DEA-Fuzzy MCDM hybrid approach
[88]	To use and compare the Qualitative TOPSIS and CKYL methods for wind farm site selection
[89]	To show the suitability map and choose the best suitable locations for wind power generation plants utilizing the GIS-AHP hybrid method
[90]	Application of GIS-MCDM hybrid method to determine appropriate areas for wind turbine installation
[91]	To explore feasible locations for offshore wind farms for coastal regions of Turkey with the GIS-MCDM combined method
[92]	To analyze the most appropriate locations for wind farms by utilizing the GIS-Fuzzy AHP approach
[93]	To explore whether the construction of wind farms off the coast of Bahrain is a manageable renewable energy choice, to identify optimal locations by mapping and to estimate possible power generation
[94]	To explore the most suitable onshore and offshore wind power stations in Iran using the fuzzy MCDM method
[95]	To utilize a hybrid MCDM method for investment risk assessment in low wind speed sites
[96]	To evaluate alternative sites for wind farm installation using MCDM techniques SWARA, Grey EDAS and interval GRA
[97]	To suggest a method based on analytical network process and cost-benefit analysis for selecting suitable turbines in the installation and investment phase of the wind farm
[98]	Evaluation of offshore wind energy resources and determination of the most suitable areas for offshore wind power deployment
[99]	To introduce a fuzzy GIS-MCDM based method and compare the developed model with the traditional AHP-TOPSIS combined approach for offshore wind farm siting
[100]	To introduce a novel hybrid MCDM method for selection of the most suitable offshore wind turbine using improved ANP and EWM method
[101]	To point out the effects of turbulence intensity on the wind power production process and to apply GIS-based MCDM approach for wind farm location selection
[102]	To present qualitative and quantitative MCDM framework for wind farm site selection using neutrosophic ANP and PROMETHEE-TOPSIS integrated methods

[103]	To determine the most appropriate marine sites considering energy capacity with seven different wind turbine models
[104]	Investigation of the present renewable energy potential applying GIS and Fuzzy AHP and deciding on the areas where wind farms can be installed in the Aegean Sea
[105]	To introduce the newly proposed hesitant fuzzy MCDM approach for offshore wind turbine technology selection
[106]	To investigate optimal wind power plant installation areas using Grid GIS and Choquet Fuzzy Integral Methods
[107]	To analyze the wind energy potentials of the Marmara Region using TOPSIS and PROMETHEE methods
[108]	To evaluate the offshore wind power plant areas using AHP and GIS
[109]	To analyze offshore wind farm sites with hybrid Fuzzy SWARA-Fuzzy WASPAS methods
[110]	To introduce optimal offshore wind farm siting by applying the Bayesian best-worst method
[111]	To explore wind farms areas using GIS-based Fuzzy Relations and Group Decision-Making Best-Worst Method
[112]	To point out and categorize barriers to the extension of offshore wind power in India
[113]	To introduce Spherical Fuzzy AHP (SF-AHP) and WASPAS hybrid method for wind turbine supplier selection

The distribution of the analyzed publications by year is given in Figure 4.

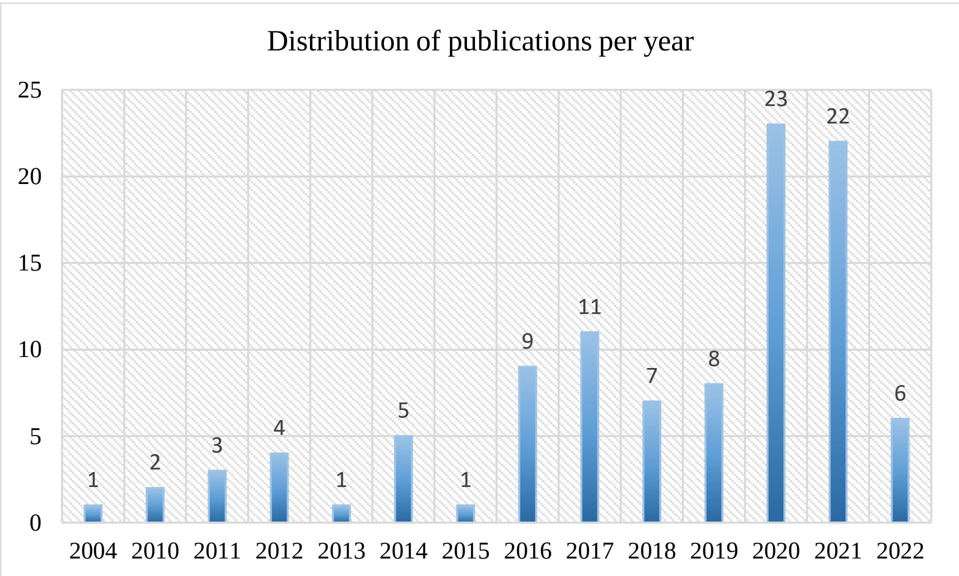

Figure 4. *Distribution of publications on wind energy by years*

According to Figure 4, while there are few studies between 2004 and 2019, it is seen that there is a significant increase in the number of studies in which MCDM methods related to wind energy are applied in 2020. Among the studies examined within the scope of the research, the number of studies published in 2021 is close to the number of studies in 2020.

The distribution of the types of studies between 2004-2022 is given in Figure 5.

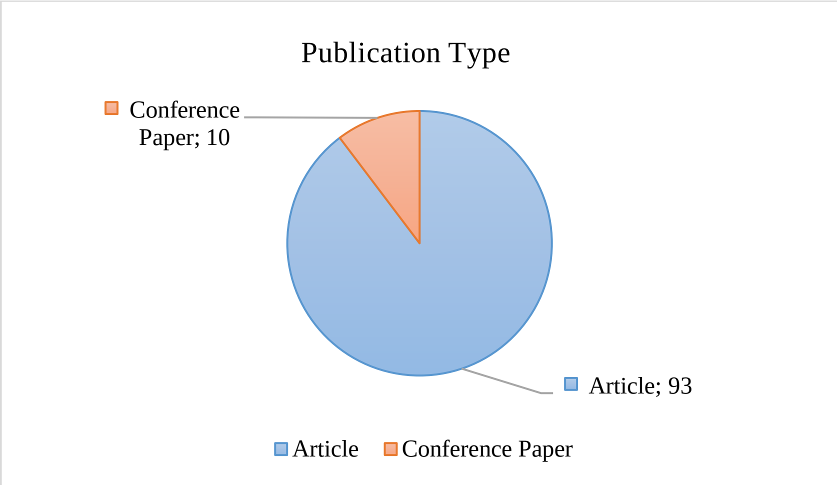

Figure 5. *Distribution of study type*

Among the 103 studies examined in this research, approximately 90% of the publications are articles, and the rest are conference proceedings. Distribution of studies based on subject areas are given Figure 6.

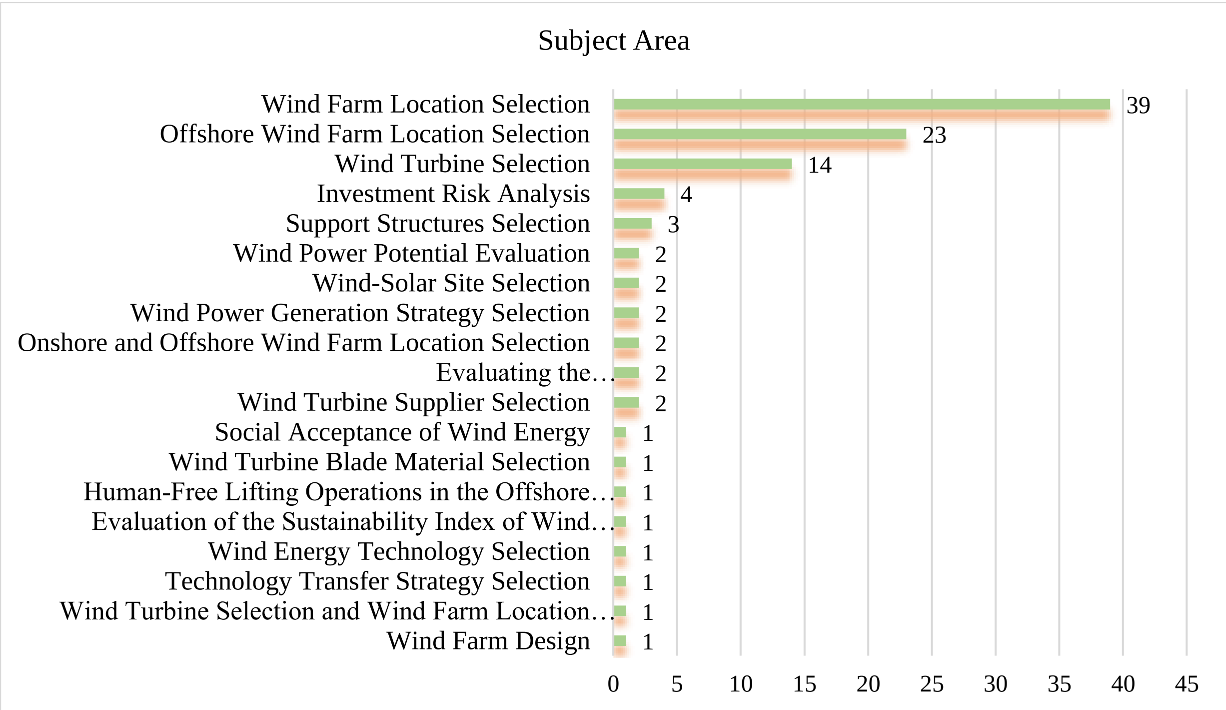

Figure 6. *Subject areas of publications*

When the distribution of the studies according to the subjects is analyzed, it can be said that most of the studies (approximately 60%) were made on site selection, followed by the topic of wind turbine selection. It is seen that approximately 74% of 103 studies were gathered under the titles of "Wind farm location selection," "Offshore Wind Farm Location Selection," and "Wind Turbine Selection."

The first 15 sources with the most publications are given in Figure 7.

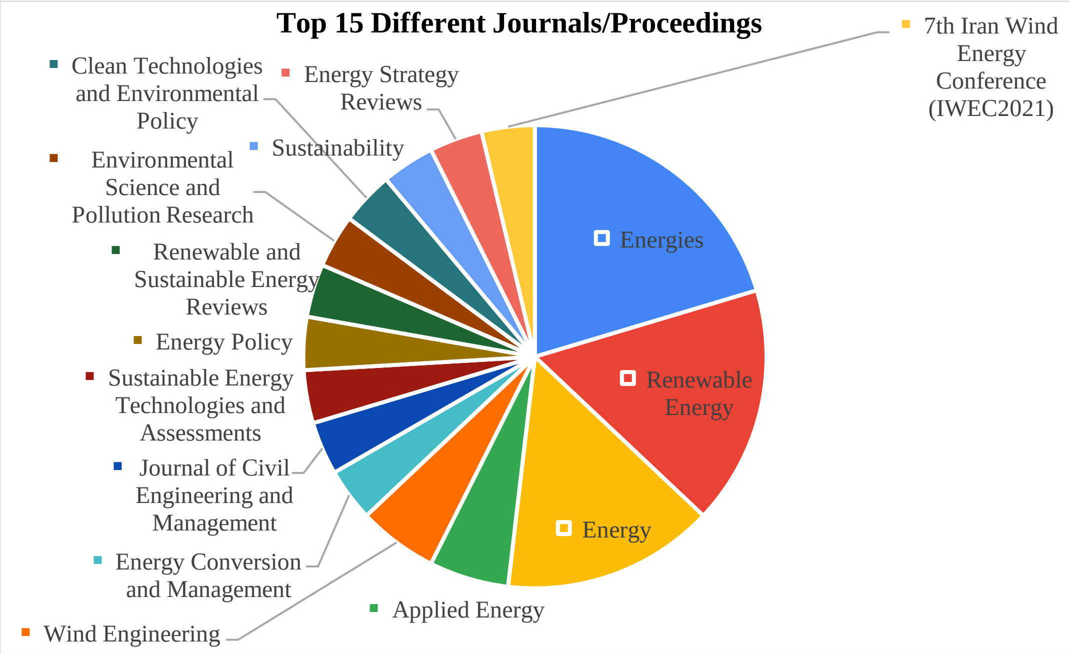

Figure 7. *Top 15 journals/proceedings*

The first three of the journals in which studies with MCDM approaches on wind energy are published the most are “Energies”, Renewable Energy” and “Energy”.

The distribution of all reviewed publications by publishers is presented in Figure 8 below.

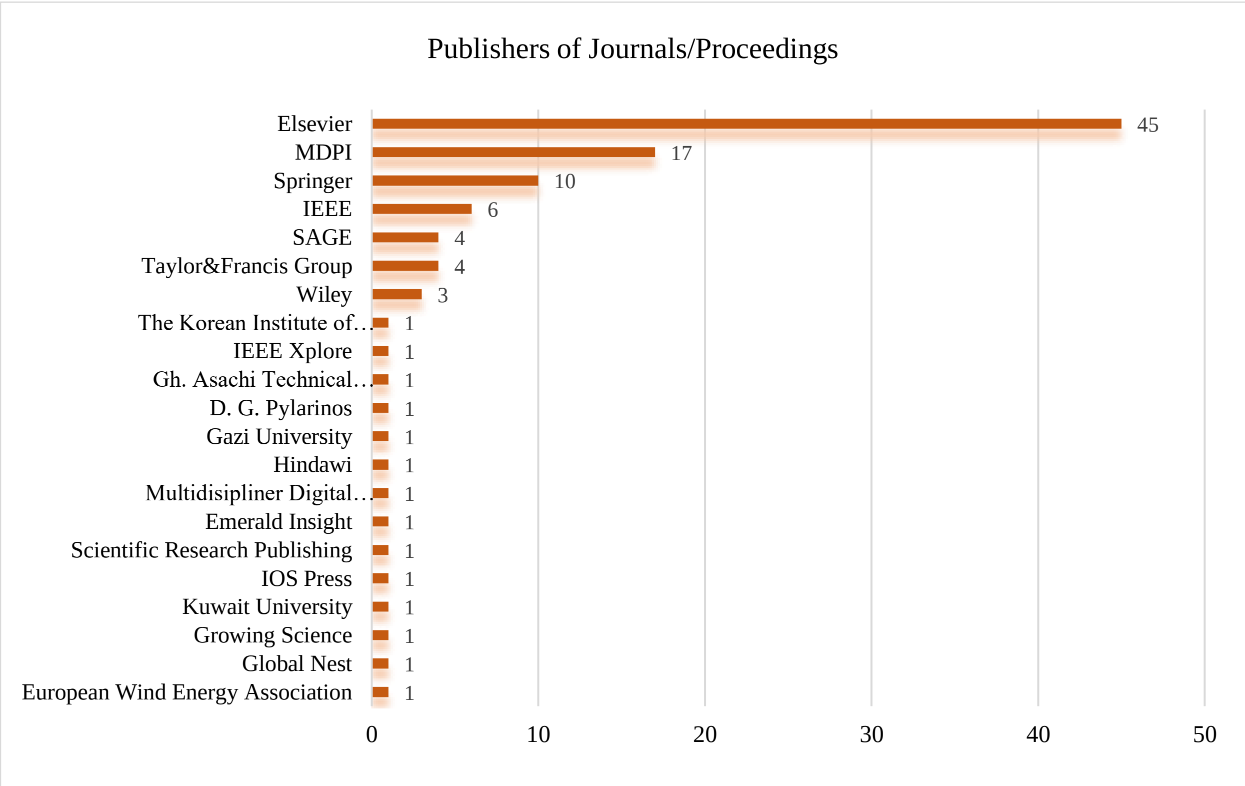

Figure 8. *Publishers of reviewed journals/proceedings*

The results of the analysis according to the publishers show that more than two-thirds of the studies examined in this study were published by Elsevier, MDPI and Springer publishers.

The citation status of the selected publications at the date of this study/review is given in Table 2. The citation numbers for articles are extracted from the Google Scholar source.

Table 2. *The number of citations of the reviewed papers*

Citation Interval	Citation	Reference
> 200	5	[11], [12], [13], [14], [15]
151-199	4	[16], [17], [18], [19]
101-150	6	[20], [21], [22], [23], [24], [25]
51-100	14	[26], [27], [28], [29], [30], [31], [32], [33], [34], [36], [37], [39], [40], [41]
1-50	68	[35], [38], [42], [43], [44],[45], [46], [47], [48], [49], [50], [51], [52], [53], [54],[55], [56], [57], [58], [59], [60], [61], [62], [63], [64],[65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76], [77], [78], [79], [80], [81], [82], [83], [84],[85], [86], [87], [88], [89], [90], [91], [92], [93], [94] [95], [96], [97], [98], [99], [100], [101],[102], [103], [105], [108], [112], [113]
0	6	[104], [106], [107], [109], [110], [111]
TOTAL CITATION	**4904**	

In the study covering the years 2004-2022; it has been determined that 5 publications have one author, 24 publications have two authors, 24 publications have three authors, 27 publications have four authors, 14 publications have five authors, 8 publications have six authors and a publication has seven authors. A total of 289 authors/researchers participated in 103 publications; 281 of authors from universities at 82 countries in total contributed to these studies. There is no definite information about 4 of them. The distribution of the authors of the 103 published studies is presented in Table 3.

Table 3. *Distribution of the authors of the reviewed studies by country*

Country	Number of Authors	Country	Number of Authors	Country	Number of Authors
Turkey	49	Saudi Arabia	9	Ecuador	4
China	37	India		Italy	
Iran	26	Nigeria	8	Malaysia	
United Kingdom	19	Egypt	8	Oman	
Spain	18	USA	7	Thailand	
Taiwan	17	Morocco		No Info.	4
Greece	12	Germany		Other	45

When Table 3 is analyzed in the context of Figure 3, it is seen that the countries where the studies published and the existing wind power plants do not meet each other linearly. The main reason for this may be the wind energy potential of the countries, the interest in renewable energy sources, and the lack of information sharing among countries.

The authors/researchers who have published the most on wind energy with MCDM techniques (Within the scope of the articles selected in this study) is presented in Table 4.

Table 4. *Authors with the largest number of publications on MCDM techniques and wind energy*

Author/Researcher	Affiliation	Number of Pub.	Reference
Shafiqur Rehman	Center for Engineering Research, Research Institute, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia	6	[23], [44], [67], [73], [79], [86]

Athanasios J. Kolios	Offshore Process & Energy Engineering Department, School of Engineering, Cranfield University, Bedfordshire, United Kingdom	5	[15], [42], [45], [55], [81]
Salman A. Khan	College of Computing and Information Sciences, Karachi Institute of Economics and Technology, Karachi, Pakistan		[44], [67], [73], [79], [86]
Ali Mostafaeipour	Industrial Engineering Department, Yazd University, Yazd, Iran	4	[50], [54], [59], [80]
S.S.H. Dehshiri	Department of Mechanical Engineering, Sharif University of Technology, Tehran, Iran		[50], [59], [80], [109]
S.J.H. Dehshiri	Department of Industrial Management, Faculty of Management and Accounting, Allameh Tabataba'i University, Tehran, Iran	3	[50], [59], [80]
Kuaanan Techato	Faculty of Environmental Management, Prince of Songkla University, HatYai, Songkhla, Thailand		[24], [59], [80]
Mehdi Jahangiri	Department of Mechanical Engineering, Shahrekord Branch, Islamic Azad University, Shahrekord, Iran		[50], [54], [80]
Muhammet Deveci	Computational Optimization and Learning Lab, School of Computer Science, University of Nottingham, Nottingham, United Kingdom		[39], [68], [71]
Ye Xu	MOE Key Laboratory of Regional Energy and Environmental Systems Optimization, College of Environmental Science and Engineering, North China Electric Power University, Beijing, China		[47], [70], [106]

27 types of MCDM Methods (AHP, ANP, OWA, SWARA, WASPAS, ISM, DEMATEL, ELECTRE, TOPSIS, SAW, COPRAS, VIKOR, TOPSIS, EDAS, GRA, SMAA, DEA, PROMETHEE, ENTROPY, EWM, MACROS, ARAS, CRITIC, MAUT, BWM, BORDA, OCRA) were used as in original form, as in fuzzy form and/or by integrating two or more methods in different ways. Geographic Information Systems (GIS) were used in 30.1% of these studies. Detailed information is presented in Table 5.

Table 5. *Classification of MCDM methods*

MCDM Method (Original Form)		**Number of Pub.**	**MCDM Method (With Fuzzy Numbers)**		**Number of Pub.**
AHP	[13], [22], [23], [24], [25], [28], [33], [38],[40], [41], [43], [46], [48], [51], [52], [53], [56], [62], [63], [83], [89], [93], [98], [101], [103], [108]	26	Fuzzy AHP	[21], [64], [85], [92], [112]	5
TOPSIS	[15], [45], [79]	3	Fuzzy TOPSIS	[32], [75]	2

Stochastic TOPSIS	[42], [81]	2	Fuzzy Logic Based MCDM Approach	[44], [54], [67], [86]	4
PROMETHEE	[29], [65]	2	COPRAS-F	[35]	1
WASPAS	[26]	1	Fuzzy ANP	[19], [31], [66]	3
ELECTRE III	[16]	1	Fuzzy DEMATEL	[19], [30]	2
O-AHP	[58]	1	Fuzzy SWARA	[109]	1
ANP	[97]	1			

Table 5. *(Continued)*

HYBRID MCDM Methods (Integrated)					
AHP+Fuzzy AHP+TOPSIS	[60]	1	SWARA+I-GRA+Grey EDAS	[96]	1
ISM+BOCR+ Fuzzy ANP	[31]	1	SWARA+EDAS+ARAS+TOPSIS+VIKOR	[50]	1
SWARA+ WASPAS	[76]	1	FAHP +Fuzzy VIKOR	[70]	1
Fuzzy ANP+ Fuzzy DEMATEL+ Fuzzy ELECTRE	[19]	1	AHP-SMAA	[74]	1
Fuzzy TOPSIS+ Fuzzy AHP	[18]	1	DEA+FAHP+ FWASPAS	[87]	1
AHP+TOPSIS	[36], [49]	1	AHP+ PROMETHEE-II	[34]	1
AHP+OWA	[17], [84]	2	AHP-TOPSIS	[99]	1
SAW+ TOPSIS+ COPRAS	[57]	1	ANP+ Entropy Weight Method (EWM)	[100]	1
Fuzzy ANP+TOPSIS	[66]	1	BWM+MARCOS	[68]	1
Interval Type 2 F. DEMATEL+ Interval Type 2 F. VIKOR+ Interval Type 2 F. TOPSIS	[30]	1	P-GRA+Grey DEMATEL+ANP	[77]	1
IAHP+Stochastic VIKOR	[47]	1	ANP+ PROMETHEE+ TOPSIS	[102]	1
Fuzzy TOPSIS+Fuzzy COPRAS	[37]	1	NWHF-CRITIC+ NWHF-MAUT	[105]	1
SWARA+TOPSIS +EDAS	[61]	1	SWARA+EDAS	[80]	1
Fuzzy TOPSIS+Fuzzy CODAS	[39]	1	TOPSIS+PROMETHEE	[107]	1
AHP +Entropy Weight	[78]	1	ISM+Fuzzy ANP	[27]	1

Method+Fuzzy TOPSIS					
Fuzzy-SWARA+Fuzzy-WASPAS	[109]	1	Best-Worst Method (BWM)+ GIS-Based Fuzzy Logic Relations	[111]	1
Spherical Fuzzy AHP (SF-AHP) WASPAS	[113]	1			

While examining the problem/research topic, the review/search starts with the keywords and abstracts. In this context, reading the abstracts and keywords save a lot of time for authors/researchers. Abstracts and keywords of all 103 publications within the scope of this study include the words "multi, criteria, wind". When the words "multi, criteria, decision, making, GIS" and the names of the methods are excluded, the distribution of the keywords and the percentages of the keyword numbers of the studies are given in Table 6. For example, 35 % of the 103 studies were published with 5 keywords. The same is true for abstracts.
Table 6 should be interpreted as follows: In the selected 103 academic studies, the word "wind" was written in the first place among the keywords in 45 studies. In addition, although it changes according to the policies of the journal in which the studies are published, a keyword line containing a maximum of 9 words has been determined.

Table 6. *The distribution of the keywords and the percentages of the keyword numbers of the studies*

Keyword	**Key Word Order**								
	1 **-**	**2** **-**	**3** **8 %**	**4** **17%**	**5** **35%**	**6** **32%**	**7** **4%**	**8** **3%**	**9** **1%**
wind	45	24	14	9	13	6	3	1	-
farm	15	2	4	4	5	2	1	-	-
off shore	13	2	2	1	3	2	-	-	-
on shore	13	2	2	1	1	2	-	-	-
site	1	5	7	1	3	1	-	-	-
renewable	12	2	2	-	2	1	-	-	1
sustainable	1	1	-	1	3	1	-	-	-
location	3	1	2	-	1	-	-	-	-

3. CONCLUSIONS

Wind energy is a renewable energy resource gaining importance due to its low cost, no carbon emissions, being a clean energy source, and contributing to sustainable development. With the increase in the importance given to renewable energy; studies on deciding where wind farms will be established, investment decisions, wind turbine selection have increased. Decision-makers often must obtain a result by considering conflicting criteria when evaluating alternatives. MCDM techniques include methods that try to reach the most appropriate solution for conflicting criteria. In this study, 103 studies using MCDM methods on wind energy were reviewed, and a comprehensive framework was presented to researchers that will work on this subject. As a result of the research, it was seen that the country with the highest onshore wind power investment in China with approximately 39%. The UK ranks first in offshore wind farm investments with 29%. It was followed by China with 28.12%. Approximately 50% of the 103 studies reviewed were published in 2020, 2021 and 2022. More than two-thirds of the studies reviewed in this study were published by Elsevier, MDPI, and Springer publishers. In addition, with the statistical analyze carried out, remarkable information such as the most used keywords of the studies, the most used MCDM methods, the distribution of the studies by country and their subject areas were revealed. According to the best of our knowledge, this is the first review article to comprehensively evaluate studies in which wind energy and MCDM methods are used together.

The study has some limitations. In order to overcome these limitations, suggestions can be given. First, only the studies in which MCDM methods are applied to wind energy are focused in this study. The scope of the study can be expanded by including other renewable energy types such as hydroelectric energy, geothermal energy and solar energy in future studies. In addition, the study focused only on articles and conference papers in English. Resources in other languages and other academic studies such as books and book chapters may be included. In addition, while the study can be expanded with other renewable energy sources, it can also be limited regionally according to its source or excluding study multi-criteria decision making methods; it can also be done in the form of a literature review that includes mathematical models or feasibility studies.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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