Journal of Engineering Research Innovation and Scientific Development 3 (1), (2025), 23-33 https://doi.org/10.61448/jerisd31253

Journal of Engineering Research Innovation and Scientific Development
journal homepage: www.jerisddelsu.com
Print ISSN 2971-6594 Online ISSN 2971-6608

Optimal Site Selection for Wind Power Plant Placement: A Case Study of Northern Nigeria using Multi Criteria Decision Making Method

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ARTICLE HISTORY

Received: 06-01-25
Revised: 18-02-25
Accepted: 24-02-25
Published: 28-02-25

ABSTRACT

This research aimed to select the optimal wind farm sites in northern Nigeria using multiple criteria decision-making (MCDM) methods, specifically the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The study examined 19 states in northern Nigeria based on 12 influential factors: wind speed, annual rainfall, average temperature, relative humidity, population, population density, area, power lines, public transmission networks and substations, road networks, altitude, and estimated capacity. The Shannon Entropy Method (SEM) was used to determine the weight of each criterion. Population density with a value of (0.0868111) had the highest weight, while average temperature with the value of (0.0813357) had the lowest. The MCDM method, TOPSIS, was used for site selection. The TOPSIS results revealed Taraba State as the best location for a wind farm with a performance efficiency of 0.9892. Niger and Borno States followed with performance efficiencies of 0.8881 and 0.8273, respectively. Kano State, with a performance efficiency of 0.0076, was identified as the least desirable state. Overall, despite various factors affecting wind farm development, the research highlights that significant portions of northern Nigeria present strong potential for wind farm suitability. The findings suggest that Taraba State is the optimal location for wind farm development, while Kano State is the least suitable option.

Keywords: Wind Energy, Optimal site selection, TOPSIS, Multi-Criteria Decision Making Method

1. Introduction

The global imperative to transition towards sustainable and renewable energy sources has intensified in response to the escalating challenges posed by climate change, energy security, and environmental degradation (Energy Information Administration, 2021). Within this context, wind energy has emerged as a pivotal component of the clean energy transition, offering significant potential for reducing greenhouse gas emissions, diversifying energy portfolios, and enhancing energy security **(Global Wind Energy Council,** 2020). Nigeria, Africa's most populous nation and largest economy, stands at a critical juncture in its quest to meet the dual objectives of economic development and environmental sustainability (World Bank, 2020).

In Nigeria, a more significant percentage of electricity is yet being generated using fossil fuels (Edomah, 2016). At present, Nigeria's electricity generation floats around 12.5GW for all sources (thermal and hydro), with only 3.5GW to 5.0GW typically available for onward transmission to the final consumer (Adekitan et al., 2018; Adesanya and Pearce, 2019; Adetokun et al., 2018). This present generating capacity is highly inadequate for a country that has a population of over 200 million (World Meter, 2020). The massive shortage in electricity supply as compared with the people has led to higher energy poverty and a low standard of living, most notably in the rural areas of the country (Njiru and Letema, 2018).

As the nation grapples with the need to address energy poverty, mitigate the adverse impacts of fossil fuel dependency, and achieve its climate commitments under the Paris Agreement, the exploration and exploitation of indigenous renewable energy resources have assumed heightened importance (Nigeria Export Processing Zones Authority, 2019). Nigeria's renewable energy landscape is characterized by abundant solar irradiation, hydropower potential, biomass resources, and significant wind energy resources (Adaramola et al., 2014).

Of particular relevance is the wind energy potential concentrated in the northern regions of the country, where vast expanses of flat terrain and favorable wind regimes offer conducive conditions for wind energy development (Oluleye et al., 2019). The Nigerian Electricity Regulatory Commission (NERC) estimates the country's wind energy potential at over 13,000 MW, predominantly located in the states of Kano, Kaduna, Sokoto, Katsina, Jigawa, and Zamfara (NERC, 2018). Despite this considerable resource endowment, the contribution of wind energy to Nigeria's electricity mix remains negligible, with only a handful of small-scale wind power projects in operation (Adefila et al., 2020).

The under-utilization of wind energy in Nigeria can be attributed to various factors, including policy and regulatory uncertainties, inadequate infrastructure, financial constraints, and technical challenges associated with wind energy integration into the grid (Ajayi et al., 2017). Furthermore, the lack of comprehensive strategies for wind farm siting and appropriate turbine selection poses significant barriers to the deployment of utility-scale wind energy projects in the country (Abubakar et al., 2020). Successful wind energy projects hinge not only on the availability of wind resources but also on the careful selection of wind turbine technologies tailored to local environmental conditions, energy demand profiles, and project economics (Adaramola et al., 2014).

Moreover, the identification of suitable sites for wind farm installation necessitates meticulous assessment of wind resources, land availability, environmental considerations, and socio-economic factors (Oseni et al., 2018). In recent years, advancements in wind turbine technology and methodologies for wind resource assessment have expanded the scope of possibilities for wind energy development in Nigeria (Akinyele et al., 2022). Innovations in turbine design, materials, and control systems have led to improvements in energy conversion efficiency, reliability, and cost-effectiveness (GWEC, 2020).

This study focuses on the optimal site selection process for wind farm siting across Northern Nigeria, employing a Multiple Criteria Decision-Making (MCDM) method. By integrating various criteria and preferences into a systematic decision-making framework, MCDM facilitates the identification of optimal solutions that align with the objectives and constraints of wind energy projects.

Energy is among the essential needs of economic development (Oyedepo et al., 2012; Babatunde et al., 2020; Somefun et al., 2020) in meeting the world's high energy demand. The significant sources of energy in use have been conventional fossil fuels (Mohammadi et al., 2014; Akporhonor and Otuagoma, 2023). The quest to cut down on the use of fossils due to their fast depletion, detrimental environmental and health influences, unstable prices, and the daily increase in energy demand has motivated the need for alternative cleaner energy resources (Li et al., 2019; Somefun et al., 2019). Also, the adverse effect of fossil fuels and the increase in energy demand have turned all eyes towards renewable energy sources (Akporhonor. et. al. 2023). In recent years, the use of wind energy for the generation of electricity has gained more acceptance all over the world due to its abundance, affordability, cleanliness, inexhaustibility, and environmental friendliness (Adetokun et al., 2020). Other advantages include the fact that its installation requires little or no maintenance and has no political or geographical boundaries. Among the renewable energy sources, wind energy is known for its fastest-growing characteristics in both developing and developed countries (Arıoğlu et al., 2015; Adetokun et al., 2018). While developing countries are still striving to harness the abundance and environmental friendliness of the renewable energy resources, some developed countries like Germany, Spain, the United States of America, China, and Denmark have proven its benefits and are still expanding the generating capacity through renewable energy technologies.

The most crucial factor to be considered when siting a wind turbine is the wind speed (Marimuthu and Kirubakaran, 2014). Another decisive factor is the total annual electricity generation from the wind. However, wind resources vary from year to year, causing the wind energy forecast to be a delicate operation. Assessing the wind energy production of a particular location requires, firstly, meteorological measurement for a considerable period for an accurate prediction of the potential of energy available on that site (Hulio et al., 2017). Based on measured data, statistical methods are applied to describe the wind resource features, and then the wind power density available at the site is evaluated. In order to conduct, rank, and optimize a suitable place for renewable energy in Northern Nigeria, choosing the right place plays an important role in the optimal use of renewable energy sources. Wind energy is one of the most important sources of renewable energy in the world due to its cost – effectiveness as well as environmental issues.

Villacreses et al. (2017) and Mahmoudi et al. (2021) use Multiple Criteria Decision-making Methods (MCDM) for resolving problems with contradictory and complicated multi-layered indices (e.g., pros and cons) that are applied. These methods rank the options and specify the best one. Multiple criteria decision-making methods have been widely used in wind farm site selection by various researchers. Höfer et. al. (2016), used Analytical Hierarchy Process (AHP) MCDM approach for selecting the appropriate wind farm site in the study of Aachen, a city in Germany. Their results revealed that the northern and middle regions are more suitable for wind farm site than other areas. Wu et. al. (2019) used the TODIM for selecting the optimal offshore wind site. Their result shows that Qingtian Bayin Zhoushan in China is the best location to effectively site a wind farm. Daneshvar. (2018) also used the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) FUZZY & Industrial and Financial System (IFS) in selecting a wind site in Turkey. His results showed that Izmir is the best location to establish wind sites. Wu et. al. (2016) made use of Elimination and Choice Expressing Reality (ELECTRE) in selecting an overseas wind site in China; their research implements the evaluation method for selecting the offshore wind farm site and provides a theoretical basis for China's offshore wind energy decisions. Watson and Hudson (2015) used the AHP & Geographic Information System (GIS) to investigate a large area of the United Kingdom, specifically Southern England, to choose a wind or solar site. Their results revealed that their studied area is more suitable for solar energy than wind energy. Sánchez–Lozano et. al. (2014) used ELECTRE and GIS in the identification and selection of potential sites for the development of coastal wind farms in the region of Murcia in Spain. The study reveals that none of the areas of interest meet the requirements. Mahdy et. al. (2018) made use of AHP & GIS in selecting an offshore site in the Red Sea in Egypt. The authors concluded that three proper areas with fair winds near the Red Sea were identified with minimal constraints.

The possibility of generating electricity through the use of wind in Nigeria has been extensively reported.

Akporhonor et. al. (2023) studied the Nigerian wind energy status and reported that wind energy potential can effectively cater to the Nigerian energy needs. Oyedepo et al. (2012) explored wind features and their energy potential for three different locations in the southeastern part of Nigeria for 27 years of data at the height of 10 m. Adaramola et al. (2014) investigate the performance of wind turbines for the generation of electric energy in southern Nigeria. Ayodele et al. *(2018)* conducted an investigation of the techno-economic viability of water pumping through the use of wind energy in southern Nigeria. Ohunakin et al. (2012), analyzed the cost estimate for wind turbines in generating electricity within six selected high-altitude locations in Nigeria. Ajayi et al. (2014) assessed the techno-economics of wind turbines in generating electricity in ten areas in southern Nigeria. Ignatius et. al. (2020) conducted a techno-economic assessment of wind turbines and recommended that wind energy potentials of some selected high-altitude and coastal areas in Nigeria should be assessed for possible utilization for the generation of electricity. Satkin et. al. (2018), using GIS & AHP on selecting the proper location for wind farm development in Nigeria, concluded that the best place to create and develop wind farms is in Northern Nigeria.

However, researches by different authors have been focused on identifying suitable locations, selecting an appropriate wind farm turbine, and determining the unit cost of energy across various places all over the world. This present study does not only identify suitable sites but also determines the effect of varying hub height on the unit cost of energy, thereby giving economic insight in making a useful decision on the generation of optimal wind energy investment in Northern Nigeria. Northern Nigeria has the highest population density and land mass among all the geopolitical zones in Nigeria, and also most of its parts are desert area. Moreover, due to unfavorable climatic conditions, the possibility of agriculture is less in many parts of Northern Nigeria, such as Plateau, Kano, Katsina, Jigawa, and Sokoto. Therefore, there is much usable land in many parts of Northern Nigeria, located near the country's' capital (Abuja) and other African countries, such as Chad and Niger. The construction of fossil power plants, such as steam, combined cycle power, and plants, seems very irrational due to high water consumption, pollution, and contradiction with the hot and dry climate of these states in Northern Nigeria. For the above reasons, renewable sources, namely wind energy, seem a very reasonable and justifiable option. Criteria and sub-criteria were specified to evaluate the wind farm potential in these states. To solve this decision-making problem, the Shannon Entropy Method (SEM) will be employed to weigh and compare the criteria. The main selected criteria for this study are wind speed, annual rainfall, average temperature, relative humidity, population, population density, area, number of power lines, number of public transmission networks and substations, number of good road networks, altitude, and estimated capacity. These criteria were chosen according to similar previous studies and the opinion of the experts. Finally, the state with the most potential to be selected for a wind turbine farm will be chosen using the technique for order of preference by similarity to ideal solution (TOPSIS) method and weighting index of the criteria.

2. Methodology

2.1 Description of Study Area

Northern Nigeria is the largest region in the giant and heart of Nigeria. She makes up over 70% of the landmass of Nigeria at about 730,000 square kilometers, with over 75 million people living in the area. Historically, Northern Nigeria is a diverse land with rich natural potentials, beautiful climate, rich culture and fertile grassland (Shehu et. al., 2015). The region is located within Nigeria, from the west coast Africa "latitude 4' and 14' east of the Greenwich Meridian (13): sharing a border with the Gulf of Guinea (Atlantic Ocean) to the south: to the west by the Benin Republic: Cameroun to the east, Chad and Niger Republic to the north. Northern Nigeria to be specific is at a latitude of 110 19'48" (11.330) north, longitude of center 60 53' 24" (6-890). As shown in Figure 1, the northern region of Nigeria comprises 19 states, including Jigawa, Kano, Katsina, and others.

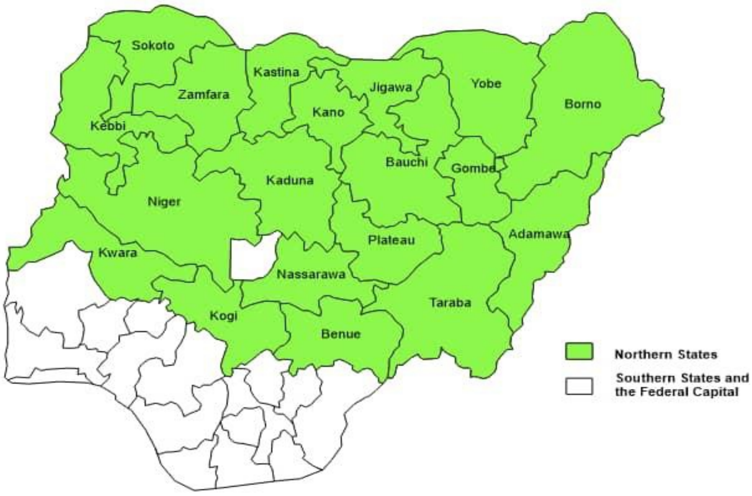

Figure 1: Map showing the 19 Northern states in Nigeria *(Sarki et al., 2020).*

2.2 Choosing the Decision Options

This research aims to select the most appropriate position for the wind farm site in northern Nigeria. Northern Nigeria is subdivided into three regions, which are northeast, northwest, and north-central, having a population of 58,539,886, 91,274,835, and 123,729,364, respectively, and a landmass of 216,065 km², 488,466 km², and 750,938 km², respectively. The north-central is the biggest in terms of landmass, followed by the northeast. The north-central is also the most populated region in northern Nigeria.

Selecting the decision options for this study, the 19 states in northern Nigeria are proposed as possible areas for wind farm sites due to their average wind speed of 4.3 m/s (15.5 km/h). The power generation in selected sites is generally from fossil fuels, gas power plants, and combined cycle. Power generation has been done, which, according to the environmental conditions of these regions, wind turbines can be a good alternative for fossil fuels to generate power. These states in northern Nigeria are assessed using MCDM, specifically TOPSIS, along with 12 different criteria, as discussed, to select the best states for a wind farm site. Furthermore, turbine efficiency rises by wind speed increase. 5 years duration of average wind speed at 100 m height was obtained from the Nigerian Meteorological Agency (NIMET) and Global Wind Atlas for the 19 northern states, as shown in Table 1 below.

Table 1: Five years' average wind speed for each states in northern Nigeria at 100m height (Sources: NIMET and Global Wind Atlas)

States/Year	2018	2019	2020	2021	2022	Average
Kano	4.3	4.2	4.3	4.4	4.2	4.3
Katsina	4.2	3.9	4.6	4.1	4.3	4.2
Kaduna	3.8	3.9	4.1	4.3	4.4	4.1
Bauchi	4.5	4.0	3.7	3.8	4.0	4.0

Jigawa	4.6	4.2	3.8	4.4	4.5	4.3
Niger	4.9	3.8	3.1	3.2	4.5	3.9
Benue	4.0	4.3	3.2	3.9	3.6	3.8
Borno	3.9	4.1	4.3	4.5	3.7	4.1
Sokoto	3.7	4.0	4.3	4.6	4.4	4.2
Kebbi	3.4	3.9	5.1	4.3	3.8	4.1
Zamfara	3.9	3.9	4.6	4.1	4.0	4.1
Plateau	3.9	3.9	4.1	4.3	3.8	4.0
Adamawa	4.0	4.0	3.7	3.8	4.0	3.9
Kogi	3.9	3.9	4.3	4.2	3.2	3.9
Gombe	3.8	3.8	4.1	3.9	4.4	4.0
Yobe	4.3	4.3	3.2	3.9	4.8	4.1
Taraba	4.1	3.9	3.9	4.1	3.5	3.9
Kwara	3.5	3.7	4.3	4.6	3.4	3.9
Nasarawa	3.9	2.9	4.2	4.3	3.7	3.8

2.3 Selection Criteria and their Evaluation

The preliminary step in the MCDM is to select the influential problem factors. Finding the most favorable site for wind farms depends on various parameters; understanding and opting for a schema will have a significant impact on the achieved results. For this study, 12 criteria with 4 effective factors (climatic, environmental, social, and technical) have been selected and studied according to similar investigations and recommendations from other resource persons. Table 2 shows the criteria and factors to choose the wind farm site. The selected criteria for this study include wind speed; annual rainfall; average temperature; relative humidity; population; population density; area (landmass); number of power lines; number of public transmission network and substations; number of good road network; altitude; and estimated capacity (Seyed et al. 2024).

Table 2: Criteria and Factors to Choose the Wind Farm Site

	Selecting the Criterion			
Factors	Climatic	Social	Environmental	Technical
Criteria	Wind Speed Annual Rainfall Average Temperature Relative Humidity	Population Population Density	Area Distance to Power lines Distance to Public Transmission Network Distance to the Road Altitude	Estimated Capacity

2.4 Decision-Making Matrix

The essential step in these methods is forming the decision-making matrix. The decision-making matrix is defined to evaluate the options. Each option is scored based on different criteria to select the optimum choice. In this research, 19 by 12 matrix consisting the 19 options (states) and 12 criteria is created as follows in Table 3.

Table 3: Decision-making matrix (Sources: Geographic information system, Nigeria Population census (2023), Nigeria Bereau of Statistics, Nigeria Renewable Energy and Energy efficiency policy (2015) and wikipedia)

S/n	States	Wind Speed (m/s)	Annual Rainfall (mm)	Average Temperature (^{0}Celcius)	Relative Humidity	Population	Population Density (people/ km^2)	Area (km^2)	Number of power lines	Number of public transmission network and substations	Average number of good roads network(km^2)	Altitude	Estimated capacity
1	Kano	4.3	650	35	0.4	16,253,549	807	20,131	234	45	32.1	700	734
2	Katsina	4.2	600	34	0.5	9,300,382	384	24,192	187	33	35.6	600	674
3	Kaduna	4.1	1100	33	0.5	8,324,285	181	46,053	283	55	29.5	500	374
4	Bauchi	4	900	33	0.5	7,540,663	165	45,837	141	24	23.2	1,200	434
5	Jigawa	4.3	700	35	0.4	6,979,080	301	23,154	156	22	18.3	500	624
6	Niger	3.9	900	35	0.5	6,720,617	88	76,363	201	38	25.9	700	404
7	Benue	3.8	1300	34	0.7	6,687,706	196	34,059	151	26	12.5	400	314
8	Borno	4.1	500	34	0.4	6,651,590	93	70,898	74	11	13.7	500	554
9	Sokoto	4.2	600	36	0.5	6,163,187	237	25,973	143	27	27.3	600	1,243
10	Kebbi	4.1	900	36	0.5	6,001,610	163	36,800	121	18	17.2	400	934
11	Zamfara	4.1	700	35	0.4	5,517,793	138	39,762	104	14	16.1	800	854
12	Plateau	4	1300	30	0.6	5,400,974	174	30,913	173	30	24.5	1,800	344
13	Adamawa	3.9	1000	32	0.6	5,236,948	141	36,917	146	26	22.1	1,500	524
14	Kogi	3.9	1300	33	0.7	5,053,734	169	29,833	134	22	11.3	800	284
15	Gombe	4	900	34	0.6	4,623,462	246	18,768	106	16	19.5	1,000	464
16	Yobe	4.1	500	35	0.5	4,350,401	96	45502	93	13	14.9	400	584
17	Taraba	3.9	1300	32	0.6	4,331,885	80	54,479	124	20	20.8	1,800	494
18	Kwara	3.9	1100	34	0.6	4,259,613	116	36,825	156	16	15.6	500	250
19	Nasarawa	3.8	1100	34	0.6	3,632,239	134	27,117	121	20	10.2	600	254

2.5 Multiple Criteria Decision-Making Methods: Problem Description

The Multiple Criteria Decision-Making **(**MCDM) method is used to resolve the planning and MCDM problems. The most important feature of these types of issues is the existence of contradicting and different standards. Various measuring units and different options are the other characteristics of these problems. The existing scales in an MCDM problem are categorized into two groups of cost and profit. The profit criteria are the ones with maximum desirable value. On the contrary, cost criteria are the ones that should be minimum. MCDM problems with option *a* and *criteria b* are represented using Equations 1 and 2, respectively.

$$X = \{x_{ij}\}_{axb} \quad (1)$$

$$W = \{w_j\}_b \quad (2)$$

where X is the decision-making matrix and W is the weighting vector. X is usually incomparable because of different criteria and various measuring units. Therefore, they should be normalized to have comparable values, Seyed et al., (2024).

2.6 Determining the Index Weight

According to Seyed et al., (2024), the weight and significance of each criterion should be first defined to apply the MCDM. There are numerous methods of weighting that are being utilized after normalization. In this study, the SEM is used for weighting.

2.6.1 Shannon Entropy Method (SEM)

One of the crucial steps in solving MCDM problems is defining the index weights. In a study by Seyed et al. (2024), the authors highlight that the entropy method is a visual method to calculate weights based on the information of the indices. The extent of the criteria's values in this method is a prominent key factor in decision-making. Greater extents in values of an index increase the importance of that index. Entropy is computed using Equation 3 (Shannon, 1948).

$$e_j = - k \sum_{i=1}^{a} p_{ij} \, Inp_{ij} \, , \, k = \frac{1}{Ina} \qquad (3)$$

p_{ij} is estimated using Equation 4

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{a} x_{ij}} \qquad (4)$$

where; x_{ij} is decision-making matrix elements, e_j is the calculated entropy value, k is a constant value, parameter a is the number of cases and p_i is the probable value of index value from the view point of ith case. In the next step, uncertainty value (d_j) and index weights (w_j) are calculated using Equation 5 and 6 respectively.

$$d_j = 1 - e_j \qquad (5)$$

$$w_j = \frac{d_j}{\sum_{i=1}^{a} d_j} \qquad (6)$$

2.7 Decision Making Model

2.7.1 TOPSIS method

The TOPSIS is a ranking method that is used to solve problems based on multiple criteria. Two solutions of positive ideal and negative ideal are defined to solve the problem. This approach tries to choose the solutions with simultaneous minimum distance to the positive ideal solution and maximum distance to the negative ideal solution. First, the criteria weights are obtained by the SEM then, the normalized matrix is obtained by multiplying the weights in the primary matrix (Seyed et al., 2024). The process of TOPSIS can be outlined in the following steps based on Hwang & Yoon (1981):

First step: normalizing the decision-making matrix using Equation 7.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{b} x_{ij}^2}} \quad , i = 1, \ldots , a \, , j = 1, \ldots , b \qquad (7)$$

where r_{ij} is the normalized value of jth criterion for ith case.

$$v_{ij} = w_j r_{ij} \quad , i = 1, \ldots , a \, , j = 1, \ldots , b \qquad (8)$$

Second step: calculating the normalized weighted matrix using Equation 8.

where wj is the ith criterion weight.

Third step: determining the positive ideal and negative ideal solutions using Equation 9 and 10 respectively.

$$A^+ = \{ v_1^+, v_2^+, v_3^+, \ldots , v_b^+ \} \qquad (9)$$

$$A^- = \{ v_1^-, v_2^-, v_3^-, \ldots , v_b^- \} \qquad (10)$$

where A^+ is the positive ideal and A^- shows the negative ideal. The optimal value for v_j^+ (positive ideal solution) is the maximum value among the positive valued criteria and the minimum value among the negative valued criteria. The optimal value for v_j^- (negative ideal solution) is the minimum value among the positive valued criteria and the maximum value among the negative valued criteria. (Yoon & Hwang, 1995).

Fourth step: calculating the distance of each case to the positive and negative ideals using Equation 11 and 12 respectively.

$$D_i^+ = \sqrt{\sum_{j=1}^{b} (v_{ij} - v_j^+)^2} \quad , i = 1, \ldots , a \qquad (11)$$

$$D_i^- = \sqrt{\sum_{j=1}^{b} (v_{ij} - v_j^-)^2} \quad , i = 1, \ldots , a \qquad (12)$$

where D_i^+ and D_i^- are the distance between the ith case and the positive and negative ideals, respectively.

Fifth step: calculating the relative adjacency and selecting the best site using Equation 13.

$$Ra_i = \frac{D_i^-}{D_i^- + D_i^+} \qquad (13)$$

where Ra_i represents relative proximity of option i.

3. Results and Discussion

3.1 Determination of entropy and weighing index

In this study, the 19 states in northern Nigeria are evaluated with 12 criteria and by applying the MCDM techniques. The SEM is implemented for weighting. After the probable values of the decision-making matrix, the parameter e_j is defined as the calculated entropy value, d_j the uncertainty value and their total is calculated as shown in Table 4 below.

Table 4: Entropy and uncertainty values

s/n	Criteria	Entropy values	Uncertainty values
1.	Wind Speed	18.2223703	-17.2223703
2.	Annual Rainfall	18.52774189	-17.52774189
3.	Average Temperature	18.22403449	-17.22403449
4	Relative Humidity	18.31607424	-17.31607424

5	Population	18.62661875	-17.62661875
6	Population density	19.38353334	-18.38353334
7	Area	18.6969938	-17.6969938
8	Number of power lines	18.53514891	-17.53514891
9	Number of Public Transmission Network and Substations	18.77776492	-17.77776492
10	Number of Good Road Network	18.60074	-17.60074
11	Altitude	19.01103532	-18.01103532
12	Estimated Capacity	18.84260588	-17.84260588
		Total	-211.7646618

The weighting index process, which is based on the dispersion of criteria, is calculated, and the results of the Shannon entropy method reveal that the criterion of population density with a weighting index of 0.0868111 has the maximum weight, followed closely by altitude and estimated capacity with weighting indexes of 0.0850521 and 0.0842568, respectively. The average temperature criterion with a weight of 0.0813357 has the minimum value. Figure 2 compares the results of the criteria and shows their comparative values on a pie chart. In addition, Table 5 shows the weighing values of the 12 criteria.

Table 5: Shannon Entropy weighing values and criteria

s/n	Criteria	Weighting index
1.	Wind Speed	0.0813279
2.	Annual Rainfall	0.0827699
3.	Average Temperature	0.0813357
4	Relative Humidity	0.0817704
5	Population	0.0832368
6	Population density	0.0868111
7	Area	0.0835692
8	Number of power lines	0.0828049
9	Number of Public Transmission Network and Substations	0.0839506
10	Number of Good Road Network	0.0831146
11	Altitude	0.0850521
12	Estimated Capacity	0.0842568

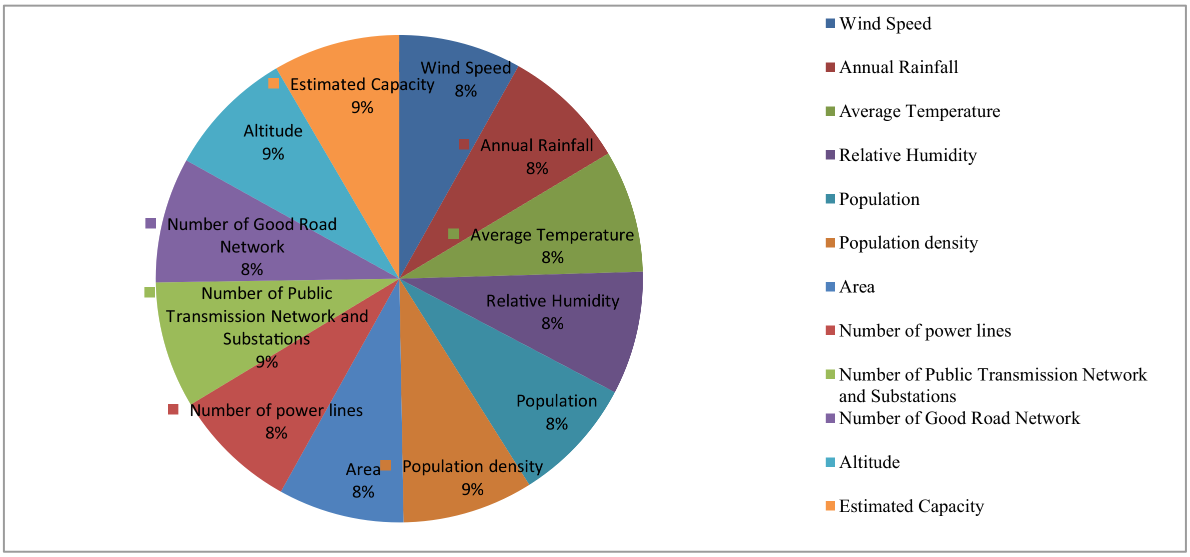

Figure 2: Shannon Entropy weighing comparison of criteria

3.2 Determination of the optimal farm turbine state by TOPSIS method

The TOPSIS method used in this study to solve problems based on MCDM involves the linear normalization of the decision-making matrix, normalizing the weighted matrix via calculation, and calculating the two solutions of the positive ideal and negative ideal defined to solve the problem. The chosen solutions with simultaneous minimum distance to the positive ideal solution and maximum distance to the negative ideal solution are then obtained. Table 6 shows the results obtained. According to the prioritizing results, the suggested site (state) of Taraba with a score of 0.989218026 is the best state to establish a wind power plant. Niger State, together with Borno State, holds the second and third positions with 0.888097573 and 0.827318989, respectively. Furthermore, Kano State, with a performance efficiency of 0.00760322, is the most undesirable state.

Table 6: Relative performance efficiency of each states by TOPSIS method

s/n	States (options)	Relative performance efficiency
1.	Kano	0.00760322
2.	Katsina	0.120329406
3.	Kaduna	0.378389839
4	Bauchi	0.42669567
5	Jigawa	0.183460846
6	Niger	0.888097573
7	Benue	0.33984928
8	Borno	0.827318989
9	Sokoto	0.26267703
10	Kebbi	0.431305279
11	Zamfara	0.526018712
12	Plateau	0.396314678
13	Adamawa	0.512710554
14	Kogi	0.411557122
15	Gombe	0.249485512
16	Yobe	0.810768763
17	Taraba	0.989218026
18	Kwara	0.652559017
19	Nasarawa	0.549149622

This MCDM shows that the most favorable state, Taraba State, which is in the northwestern part of northern Nigeria, to extract wind energy can be used for practical goals. According to the results, adjacent to environmentally restricted areas, populated areas, and a good road network makes her the optimal state with the highest wind farm potential. Although Taraba State has lower wind speed, other factors reduce the initial and maintenance costs and make the wind turbine farm siting project more justifiable and realistic.

3.3 Sensitivity Analysis

The sensitivity analysis is performed on the criteria to confirm the results' reliability and achieve more dependable results. One of the most common ways of conducting a sensitivity analysis of the cases is changing each criterion's weight and evaluating the effect of these changes on the priority of all cases. The criteria weights are altered three times in this study; then, the weight calculations are performed using the MCDM method, which is TOPSIS, to determine the new weights. According to the Shannon Entropy weighting method, the criterion of population density has a weighting index of 0.0868111 due to its high dispersion. In this study, the weight of this criterion is reduced to almost 0.00068111 to assess its effect on cases. Moreover, the weight of the average temperature criterion (which has the least weight of 0.0813357) is increased up to 0.9968171 to analyze the sensitivity. Table 7 represents the primary criteria weight (W) and the new weights of other criteria in three modes (W_1–W_3). Figure 3 shows the effect of criteria weight variations according to the results of the TOPSIS method and the rank of each case in each sensitivity analysis. In this figure, the vertical axis is the score of each case based on the TOPSIS method, and the horizontal axis is the figure of sensitivity analyses (W_1-W_3). It is deduced from the results that Taraba State is the best option throughout all three modes. As the results are highly dependent on the weights of the criteria, variations in the results of other cases are high. Therefore, the most or least desirable case cannot be identified assertively.

Table 7: Criteria weight in a sensitivity Analysis

s/n	Criteria	W	W_1	W_2	W_3
1.	Wind Speed	0.0813279	0.0893279	0.9983279	0.0973279
2.	Annual Rainfall	0.0827699	0.0887699	0.0982769	0.0857699
3.	Average Temperature	0.0813357	0.0873357	0.07883357	0.9968171
4	Relative Humidity	0.0817704	0.0867704	0.0816704	0.0897704
5	Population	0.0832368	0.0852368	0.0832368	0.0832368
6	Population density	0.0868111	0.0086811	0.0088111	0.00068111
7	Area	0.0835692	0.0845692	0.0835692	0.0835692
8	Number of power lines	0.0828049	0.0838049	0.0828049	0.0828049
9	Number of Public Transmission Network and Substations	0.0839506	0.9968171	0.0839506	0.0839506
10	Number of Good Road Network	0.0831146	0.0897704	0.0831146	0.0838049
11	Altitude	0.0850521	0.0832368	0.0850521	0.0829506
12	Estimated Capacity	0.0842568	0.0802568	0.0842568	0.0811146

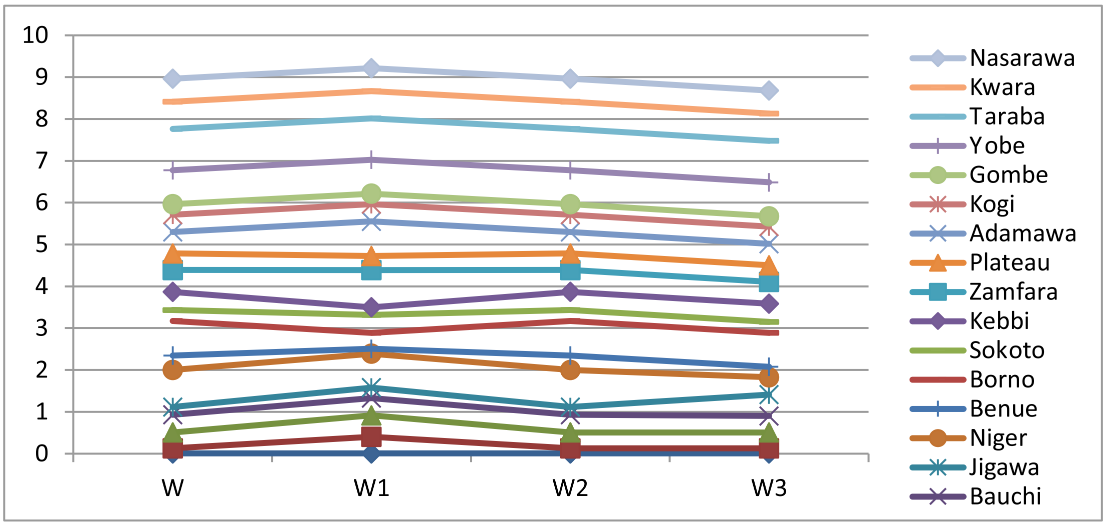

Figure 3: Sensitivity Analysis for TOPSIS Method

4. Conclusion

The national and international need for energy is on the increase along with economic and industrial development and population growth. Regarding the widespread use of fossil fuels, the provision of a portion of required electrical and thermal energies by the cities and villages using renewable energies such as wind is essential to reach the goals of sustainable development and reduced consumption of fossil fuels. The first step to using renewable energy is the identification of the appropriate places with high potential. In this study, the existing potentials in the northern part of Nigeria are investigated based on their relevant environmental, technical, social, and climate factors with 12 influential criteria, including wind speed, annual rainfall, average temperature, relative humidity, population, population density, area, number of power lines, number of public transmission networks and substations, number of good road networks, altitude, and estimated capacity, using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) with Taraba State identified as the best state to site a wind farm site with a performance efficiency of 0.989218026. Niger and Borno states are the second and third best areas for the selection of a wind farm site with relative performance efficiencies of 0.888097573 and 0.827318989, respectively. In addition, the results also show that Kano State, with a performance efficiency of 0.00760322, is the most undesirable state.

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