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Assessment of Three Selected Locations in Nigeria as Offshore Windfarms Using Multi-criteria Decision Procedure

Ezekiel Asuku MAYAKI[1], Oyewole ADEDIPE[1], Uzoma Gregory OKORO[1], Rabiu Onoruoiza MAMMAN[1], Sunday Albert LAWAL[1]

[1]*Department of Mechanical Engineering, School of Infrastructure, Process Engineering and Technology, Federal University of Technology, Minna Nigeria*

mayakionimisi@gmail.com, oye.adedipe@futminna.edu.ng, u.g.okoro@futminna.edu.ng, rabiumamman87@gmail.com, lawalsunday@futminna.edu.ng

Corresponding Author: oye.adedipe@futminna.edu.ng

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Abstract: *The continuous rise in carbon footprints arising from industrial and domestic activities has placed urgent need on renewable energy sources globally. Wind as a renewable energy source is gaining global prominence because it can be harnessed in small and commercial quantities. Several studies have been carried out on the subject of wind energy. However, this paper is focused on multi-criteria evaluation of three Nigerian coastal locations (Lagos, Port-Harcourt and Warri) for consideration for installation of offshore wind farm to improve energy availability in the country. In this paper, attributes for offshore wind farm location were collected for three locations in Nigeria; Victoria Island (VI) in Lagos, Abbonema area of River State and Koko area of Warri. Ten-year wind speed data for the three locations were also collected from the archive of Nigeria Metrological Agency (NIMET), while other required factors were collected with the use of a well-structured Questionnaire and the respondents were senior staff of the Nigerian Airspace Management Agency (NAMA) and NIMET. Collected data were analyzed using Multi-Criteria analysis tool (TOPSIS). Average of a ten-year wind speed data for Lagos (VI), Koko (Warri) and Abonemma (Rivers) were 6.251m/s, 7.294m/s and 7.347m/s respectively. Analytical Hierarchy Process (AHP) gave a Consistency Index of 0.123029264 and Consistency Ratio of 0.084266619. The consistency ratios from the AHP were used to calculate the required Criteria Weight (C_w) for the TOPSIS analysis. From the cumulative value of the analysed factors, Victoria Island (Lagos) has the highest figure of 233.6677 with a consideration rate of 38% and this places it above Koko (Warri) and Abonnema (Rivers) with a value of 187.7704 (30%) and 195.4377844 (32%). Based on the analysis carried out, Victoria Island Lagos appears to be the best option for offshore wind farm consideration.*

Keywords:*Multi-Criteria, Offshore, Pair-wise, Analytic, TOPSIS.*

1. INTRODUCTION

Consistent power supply is a necessity for social-political sustainability. The recent rise in worlds' population has made it a necessity to harness other alternatives energy sources to augment the conventional fossil fuels. Fossil fuel as a source of energy is accompanied with the emission of greenhouse gasses which in-turn has shown an adverse effect on our environment. With the current global legislation on greenhouse gas emission and the quest to achieve the Sustainable Development Goals (SDGs), such as SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), attentions are now being focused on exploiting renewable energy source since they are readily available, sustainable and environment friendly. Among the available renewable energy sources, wind energy is becoming an aspect of global focus because of its availability and sustainability. A recent report on global wind power shows that the total installed capacity of wind power had increased from 6,100 MW in the year 1996 to 597 GW in 2018 and this further proves the viability of wind as an alternative energy source [1].

The adoption of wind energy as a source of power generation is more common among the developed nations such as; Belgium, United Kingdom, China, Denmark, United States of America amongst others. The utilization of wind energy technology is still not very common in Africa, except for countries like Tunisia, Morocco and Egypt that are making good progress within the wind energy value chain in Africa [1].

In order to ascertain the viability of any location as a windfarm site, several factors need to be considered. These include feasibility study based on the recorded wind data from the location and subsequent statistical evaluation [2], cost comparative and logistic assessment [3], as well as other multiple criteria assessments.

Taking Nigeria as a case study where the idea of wind energy technology is relatively uncommon, most studies are focused on statistical characterization of potential windfarm sites while little work have been done to ascertain if the acclaimed sites are readily viable as windfarm sites in terms of other valuable criteria apart from wind energy output obtained from statistical studies. Up till date, only reference [3] has carried out a study on logistic analysis of Nigeria offshore windfarm sector. The study was focused on cost comparative assessment of realizable energy output in comparison to the conventional fossil source, different stages of installation using procedures that optimizes material transport from the coast to the offshore installation sites. In this paper, the authors intend to explore other multiple criteria analysis that influences windfarm sites using TOPSIS analysis. As such, it is hoped that the outcome of this study will attract the attention of policy makers and government agencies within the Nigerian energy sector to focus attention on developing wind power projects within the selected locations.

The selection of the appropriate offshore installation site involves a few conflicting criteria and these criteria are best resolved with the use of Multi-Criteria Decision Analysis known as the MCDA or Multi-Criteria Decision Method (MCDM) [4]. Multiple-criteria decisions making (MCDM) or Multiple-criteria decision analysis (MCDA) is a sub-discipline of operations research that explicitly evaluates multiple conflicting criteria in decision making (both in daily life and in settings such as business, government and medicine) [5]. Conflicting criteria are typical in evaluating options; cost or price is usually one of the main criteria. However, some measure of quality is typically another criterion, easily in conflict with the cost [6]. In purchasing a car, cost, comfort, safety, and fuel economy may be some of the main criteria to consider. Structuring complex problems and considering multiple criteria explicitly leads to more informed and better decisions [7]. There have been important advances in this field since the start of the modern multiple-criteria decision-making discipline in the early 1960s [8]. A variety of approaches and methods, many implemented by specialized decision-making software [9] that have been developed for their application in an array of disciplines, ranging from politics and business to the environment and energy [10]. In this study, attention was focused on technical criteria such as; power demands, shipping routes, average wind speed within the considered locations and offshore distance from nearby airport.

Other related studies that have been carried out include a study reported in [11] where a state-of the-art survey of TOPSIS applications Multi-Criteria Decision Aid (MCDA) was presented. A study on site selection for wind farm installation was also carried out by [12]. Hodgett worked on Multi-Criteria Decision-Making in whole process design [13]. Studies on statistical characterization of wind speed have also been reported by [14], [15], and [16]. While in Nigeria, reference [17] carried out an assessment of wind energy alternative in Nigeria. A similar work considering Nigeria as a case study was also carried out investigating wind energy potential in Nigeria [18]. Reference [3] carried out a logistic analysis of Nigeria offshore wind farm sector while Ajayi [19] carried out the Potential for wind Energy in Nigeria. A study was also carried out to investigate wind energy potential in Mubi Adamawa, Nigeria [20]. Summarily, the reported aforementioned works have shown that Multi-Criteria Decision procedure has not been applied to investigate the potential for installation of offshore windfarms in the three selected Nigeria coastal cities that are considered in this paper.

2. METHODOLOGY

In order to ascertain the appropriateness of a location as a potential site for offshore wind farm, certain criteria must be fulfilled within the location. There are three major considerations for the selection of an appropriate site(s) for offshore wind farm. These are economical consideration, socio-political consideration and environmental consideration. Environmental consideration is further divided into two vital Multi-Criteria aspects. The first is a Multi-Criteria process concerned with the geographical nature of the selected location. A geographical information system (GIS) is majorly required to obtain all the criteria needed for analysis. It considers aquatic life, soil topography, undersea soil erosion and the change in water level. The second aspect considers the suitability of the selected location based on the immediate surroundings. This aspect is known to be the technical aspect of the environmental consideration. Attributes that are considered in this aspect are; average wind speed of the offshore region, distance from shore (Settlement), distance from Airport(s), distance from local electricity distribution companies, proximity to high power demand areas, Interference with bird flight, interference with undersea cables and gas lines, interference with existing shipping route and interference with telecommunication installations. Data collected were analysed using the TOPSIS mathematical model.

2.1 Data Collection

This study was limited to the technical attribute required for the location of a wind farm. The considered data were limited to power demand, distance from airport, average wind speed and shipping route. These data were collected for the three offshore locations; Lagos VI, Koko area of Warri and Abonemma in Rivers, which are the alternatives for which their attributes were analysed. 10 years average offshore wind speed data from 2002 to 2011 were collected from Nigeria Metrological Agency (NIMET). The data were collected using cup generator in a buoy system at 10m above sea level. The qualitative attributes were sourced for and quantitative attributes were obtained using well-structured questionnaires. Ten number samples of questionnaires were served to staff of the Nigerian Airspace Management Agency and NIMET in each of the locations under consideration, out of which eight was the least feedback.

2.2 Mathematical Model

In this study, the technique for order of performance by similarity to ideal solution was applied in resolving the multi-criteria problem [21]. TOPSIS assists decision maker(s) organize the problems to be solved; it also helps to analyse, compare and rank alternatives. Also, the Analytical Hierarchy Process (AHP) is one of the multiple criteria decision-making methods [22]. It provides measures of judgment consistency, derives priorities among criteria and alternatives and simplifies preference ratings among decision criteria using pair wise comparisons. The mathematical process used for this study is described in the following section.

2.3 Mathematical Processes

For a matrix of a pair-wise element writing as:

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} \\ C_{21} & C_{22} & C_{23} & C_{24} \\ C_{31} & C_{32} & C_{33} & C_{34} \\ C_{41} & C_{42} & C_{43} & C_{44} \end{bmatrix}$$

The sum of the values in each column of the pair-wise matrix is given in Equation 1

$$C_{ij} = \sum_{i=1}^{n} c_{ij} \qquad (1)$$

Dividing each element in the matrix by its column total to generate a normalized pair-wise matrix described as;

$$X_{ij} = \frac{C_{ij}}{\sum_{i=1}^{n} c_{ij}} \begin{bmatrix} x_{11} & x_{12} & . & x_{1m} \\ x_{21} & . & . & . \\ . & . & . & . \\ x_{n1} & . & . & x_{nm} \end{bmatrix} \qquad (2)$$

The consistency vector is calculated by multiplying the pair-wise matrix (Equation 2) by the weights vector, Equation 3 is formulated as;

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} \\ C_{21} & C_{22} & C_{23} & C_{24} \\ C_{31} & C_{32} & C_{33} & C_{34} \\ C_{41} & C_{42} & C_{43} & C_{44} \end{bmatrix} \times \begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \\ W_{41} \end{bmatrix} = \begin{bmatrix} C_{V11} \\ C_{V21} \\ C_{V31} \\ C_{V41} \end{bmatrix} \qquad (3)$$

Consistency vector average ʎmax (Average) is calculated by averaging the value of the consistency vector. This is expressed in Equation 4

$$\lambda = \sum_{i=1}^{n} Cv_{ij} \qquad (4)$$

Consistency index *CI* and consistency ratio *CR* are also expressed in Equations 5 and 6

$$CI = \frac{\lambda - n}{n-1} \qquad (5)$$

$$CR = \frac{CI}{RI} \qquad (6)$$

The structure of the decision matrix D^k is therefore expressed in Equation 7

$$D^k = \begin{array}{c} \\ A_1 \\ A_2 \\ \\ A_i \\ \\ A_m \end{array} \begin{array}{c} X_1 \quad X_2 \quad \ldots X_j \quad \ldots X_n \\ \begin{pmatrix} x^k_{11} & x^k_{12} & \ldots & x^k_{1j} & \ldots & x^k_{1n} \\ x^k_{21} & x^k_{22} & \ldots & x^k_{2j} & \ldots & x^k_{2n} \\ & & & & & \\ x^k_{i1} & x^k_{i2} & \ldots & x^k_{ij} & \ldots & x^k_{in} \\ & & & & & \\ x^k_{m1} & x^k_{m2} & \ldots & x^k_{mj} & \ldots & x^k_{mn} \end{pmatrix} \end{array} \qquad (7)$$

Ai represents the alternative i, i = 1,...,m; X_j represents criterion j, j = 1,...,n; with both numerical and non-numerical data. x^k_{ij} indicates the performance rating of alternative A_i with respect to criterion X_j by decision maker k, k =1,..., K, and x^k_{ij} is the component of D^k. Note that non-numerical data from each alternative can be assigned discrete values or linguistics values.

For easy combination of qualitative and quantitative attributes, Normalization was carried out on the data and this handles the disparity in both set of data. This was done using the corresponding excel command. Taking the average of the criteria values gives Equation 8 as:

$$Average(\mu) = \frac{\sum_{i=1}^{n} C_{ij}}{n} \quad (8)$$

The standard deviation based on samples was done using the Excel function (=STDEV.S)). This can be expressed as:

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(C_{ij} - \mu)^2} \quad (9)$$

3. RESULTS AND DISCUSSIONS

3.1 Wind Data

Figures 1, 2 and 3 show the monthly average wind speed for Lagos, Warri and Abonemma (Rivers) respectively. Table 1 shows a ten years average wind speed for Lagos VI, Abonemma (Rivers) and Koko (Warri). From Table 1, Lagos has 6.25 m/s, Port-Harcourt has the highest average wind speed of 7.35 m/s and Warri with an average wind speed of 7.29 m/s.

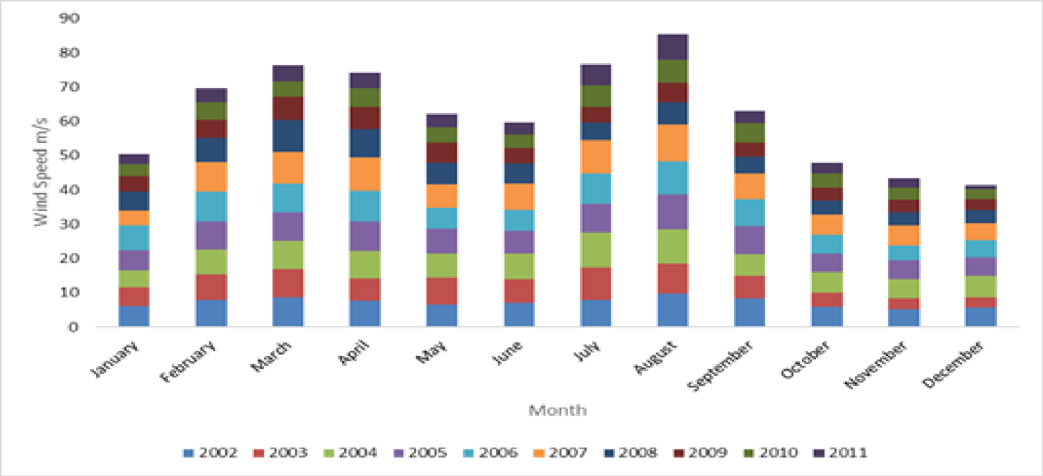

Figure 1: Chart of monthly average wind speeds in Lagos (VI) from 2002-2011

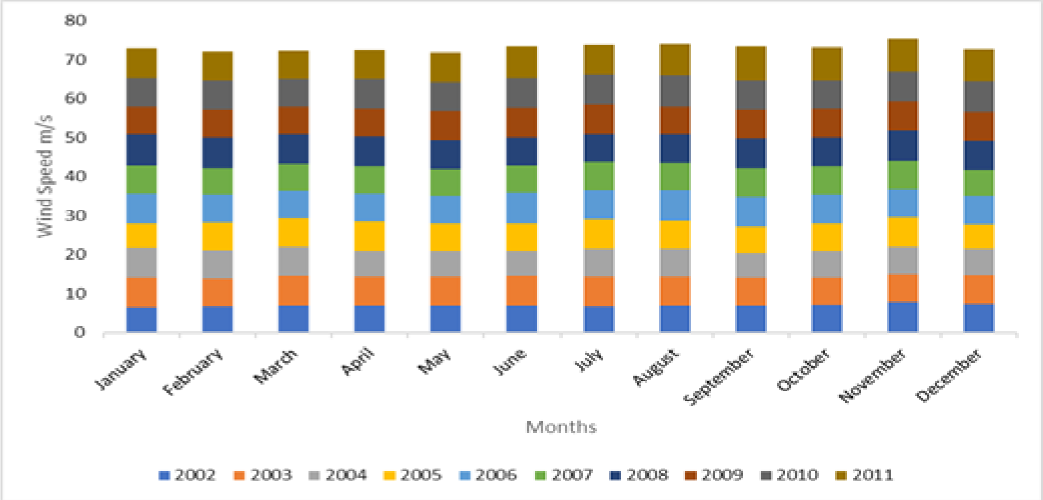

Figure 2: Chart of monthly average wind speeds in Rivers (Abonemma), 2002-2011

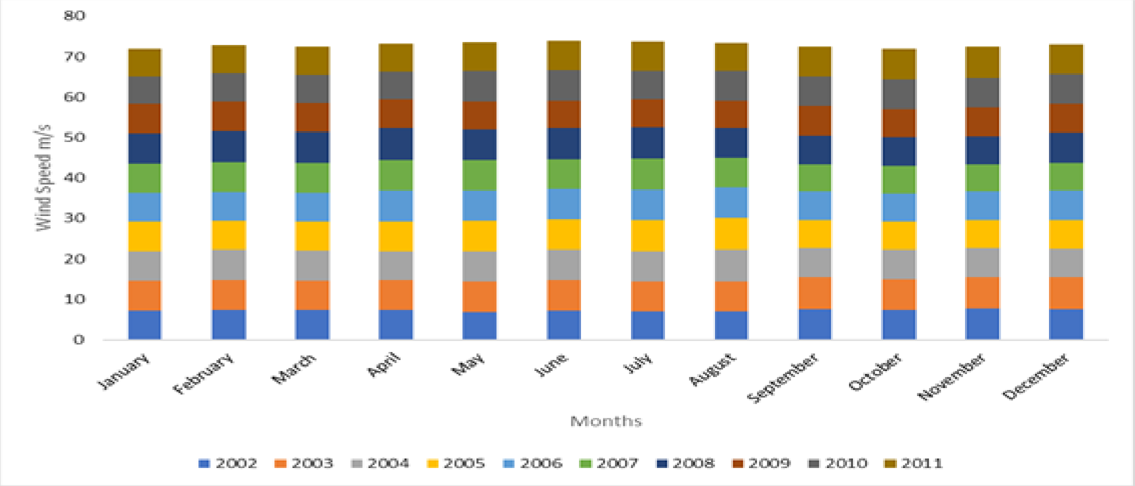

Figure 3: Chart of monthly average wind speeds in Koko (Warri) from 2002-2011

Using Table 1, Figure 4 is the combined chart for the ten years average wind speed for the three alternatives (Lagos VI, Abonemma (Rivers) and Koko (Warri).

Table 1: Ten Years Average Wind Speed (m/s) for Lagos VI, Koko (Warri) and Abonemma (Rivers)

Alternatives	Years										Average
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	
Lagos VI	7.21	6.49	7.27	7.32	7.21	7.6	5.88	4.83	4.7	4	6.25
Koko (Warri)	7.38	7.46	7.35	7.32	7.32	7.17	7.48	7.07	7.2	7.19	7.29
Abonemma (Rivers)	7.3	7.37	6.89	7.13	7.38	7.06	7.54	7.3	7.56	7.94	7.35

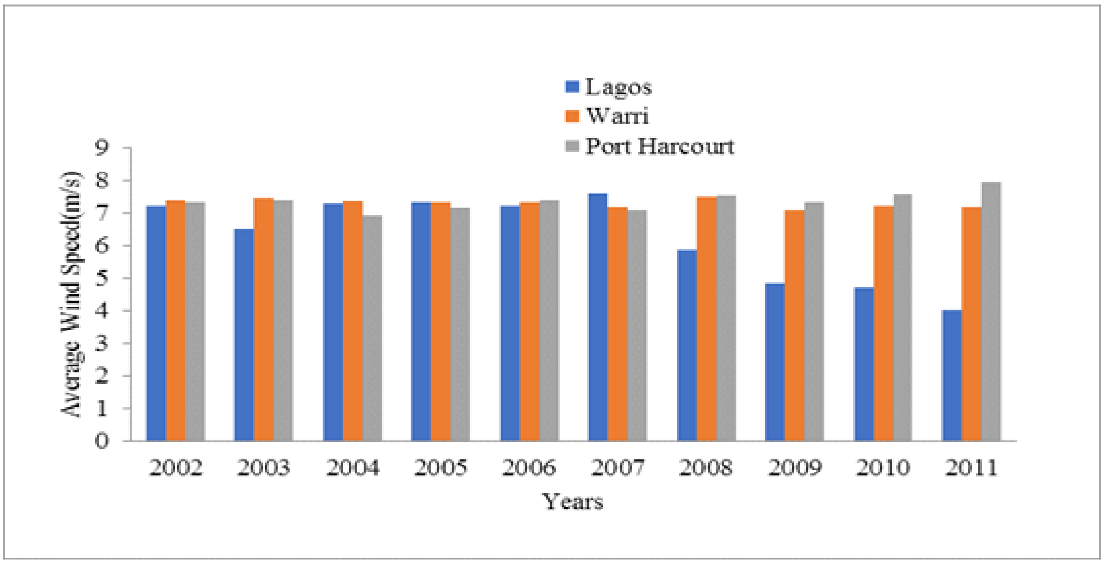

Figure 4: Combined Chart of Average Wind Speed for the three Alternatives

From Figure 4, it can be seen that Lagos VI has a large variation in wind speed for the ten years period which can be attributed to heavy activities on the Victoria island region. Abonemma (Rivers) has a steady wind speed for the ten years period and Koko (Warri) is steadier. Also, Lagos VI has 7.32 m/s as its highest wind speed which was in 2005 and lowest of 4.0 m/s in 2011, Koko (Warri) has it lowest average wind speed in the year 2009 (7.07 m/s) and highest in the year 2008 (7.48 m/s) and Abonemma (Rivers) lowest average wind speed of 6.89 m/s occurred in 2004 while the highest was in 2011 (7.94 m/s). The average wind speed for the three alternatives Lagos VI (6.25 m/s), Abonemma (Rivers) (7.35 m/s) and Koko (Warri) (7.29 m/s), implies that all of the alternatives have the required average wind speed for the installation of wind farm which is a minimum of 4.0 m/s as stated by Medugu and Malgwi [20].

3.2 Technical Aspects of the Environmental Attributes

Other required criteria for the proper evaluation of an offshore wind farm like distance from shore, distance from an airport, proximity to power demand and Local Power distribution (DISCO) companies were collected. The samples collected were sorted and rearranged as shown in Table 2, 3 and 4 for the three Alternatives. The averages were then determined for further analysis. The distance from shore was obtained from the NIMET stations in each of the locations. Lagos VI was found to be 500km, Koko (Warri) 350km and Abonemma (Rivers) was 400km. Different weights from 1 to 5 were assigned to the remaining attributes based on the outcomes from the questionnaire.

Table 2: Attribute data collected for Lagos VI

Attributes	SAMPLES								Average
	1	2	3	4	5	6	7	8	
Distance from Airport (m)	534	530	535	533	535	529	533	535	533
Distance from DISCO (m)	532	533	533	530	533	528	531	529	531.13
Power Demand	4	5	5	5	5	4	4	4	4.5
Bird Flight Interference	3	2	2	2	3	2	2	2	2.25
Shipping Route	2	2	2	1	3	1	2	1	1.75
Undersea Gas Line	2	2	3	4	3	2	2	1	2.38
Telecommunication Interference	3	4	1	4	4	4	3	3	3.25

Table 3: Attribute data collected for Koko (Warri)

Attributes	SAMPLES								Average
	1	2	3	4	5	6	7	8	
Distance from Airport (m)	437	430	440	437	435	445	437	447	533
Distance from DISCO (m)	433.3	430	435.5	425	432	437	431	431	431.85
Power Demand	5	5	4	3	4	4	3	3	3.88
Bird Flight Interference	2	2	3	1	4	2	3	3	2.5
Shipping Route	4	4	4	5	4	4	3	3	3.88
Undersea Gas Line	5	5	4	4	5	5	4	4	4.5
Telecommunication Interference	4	5	5	4	5	4	5	5	4.63

Table 4: Attribute data collected for Abonemma (Rivers)

Attributes	SAMPLES								Average
	1	2	3	4	5	6	7	8	
Distance from Airport (m)	437	430	440	437	435	445	437	447	533
Distance from DISCO (m)	433.3	430	435.5	425	432	437	431	431	431.85
Power Demand	5	5	4	3	4	4	3	3	3.88
Bird Flight Interference	2	2	3	1	4	2	3	3	2.5
Shipping Route	4	4	4	5	4	4	3	3	3.88
Undersea Gas Line	5	5	4	4	5	5	4	4	4.5
Telecommunication Interference	4	5	5	4	5	4	5	5	4.63

3.3 Analytical Hierarchy Process

The weight function was computed from the data collected. The computation was based on the AHP principle. Weights were allotted to Attributes based on their relevance in the determination of the appropriate site location.

3.3.1 Mathematical Evaluation

Some of the notations and symbols used for calculation are defined as follows:

X Decision Matrix (Judgment Matrix)
r_{ij} Normalized Decision Matrix with i^{th} number of alternative and j^{th} number of criterion
C_1 Power Demand
C_2 Distance from Airport

C_3 Average Wind Speed
C_4 Shipping route interference
C_5 Undersea Gas Line Interference
C_6 Distance from Shore
C_7 Distance from Distribution Company
C_8 Bird Flight Interference
C_9 Telecommunication Interference
W Weight
CI Consistency Index
CR Consistency Ratio
RI Random Inconsistency
μ Average of Criteria Pair-wise Matrix
σ Standard deviation
λmax Consistency Vector Average
n Number of Criteria

Table 5 shows the criterion weight score. Comparison of criteria was done and scored according to the rating on the table. When a particular criterion is compared to itself, it carries a judgment value of 1; and if two different criteria happen to have the same level of relevance, a judgment value of 1 is also assigned. When a criterion is less important than that which it is been compared to, the judgment value is taken from the right-hand side of Table 5 and an inverse of that value is recorded. However, when a criterion is more important than that which is being compared to, the judgment value is taken from the right-hand side of table 5 and the actual value is recorded.

Table 5: Effective criteria and pair wise comparison

Factor	Factor weighting Score											Factor
	More Important than					Equal	Less Important than					
C_1	1	2	3	4	5	1	1	2	3	4	5	C_2
C_2	1	2	3	4	5	1	1	2	3	4	5	C_3
C_3	1	2	3	4	5	1	1	2	3	4	5	C_4
C_4	1	2	3	4	5	1	1	2	3	4	5	C_5
C_5	1	2	3	4	5	1	1	2	3	4	5	C_6
C_6	1	2	3	4	5	1	1	2	3	4	5	C_7
C_7	1	2	3	4	5	1	1	2	3	4	5	C_8
C_8	1	2	3	4	5	1	1	2	3	4	5	C_9
C_9	1	2	3	4	5	1	1	2	3	4	5	C_1

Table 6 shows the comparison matrix of order nine (9) where 9 criteria C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8 and C_9 are compared against each other.

Table 6: Pair wise input comparison matrix

Factor	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	3	2	2	4	0.5	0.3333	0.25	0.25
C_2	0.3333	1	0.5	0.5	2	0.25	0.2	0.1667	0.1667
C_3	0.5	2	1	1	0.3333	0.3333	0.25	0.2	0.2
C_4	0.5	2	1	1	3	0.3333	0.25	0.2	0.2
C_5	0.25	0.5	3	0.3333	1	0.2	0.1667	0.1429	0.1429
C_6	2	4	3	3	5	1	0.5	0.3333	0.3333
C_7	3	5	4	4	6	2	1	0.5	0.5
C_8	4	6	5	5	7	3	2	1	1
C_9	4	6	5	5	7	3	2	1	1

3.3.2 Normalization

Normalization of the matrix is the next step immediately after matrix comparison. In equation (1), the sum of the pair-wise criteria matrix column was calculated as shown in Table 7. Using equation (2), each element in the column was divided by the column sum to return its normalized value. Summation of each column of the normalized matrix was 1, which conforms to Saaty's [22] claim that the column sum of a normalized comparison must be equal to 1. Table 8 shows the normalized form of the comparison matrix.

Table 7: Column total of the pair wise input comparison matrix

Factor	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	3	2	2	4	0.5	0.3333	0.25	0.25
C_2	0.3333	1	0.5	0.5	2	0.25	0.2	0.1667	0.1667
C_3	0.5	2	1	1	0.3333	0.3333	0.25	0.2	0.2
C_4	0.5	2	1	1	3	0.3333	0.25	0.2	0.2
C_5	0.25	0.5	3	0.3333	1	0.2	0.1667	0.1429	0.1429
C_6	2	4	3	3	5	1	0.5	0.3333	0.3333
C_7	3	5	4	4	6	2	1	0.5	0.5
C_8	4	6	5	5	7	3	2	1	1
C_9	4	6	5	5	7	3	2	1	1
Total	15.5833	29.5	24.5	21.8333	35.3333	10.6167	6.7	3.7929	3.7929

Table 8: Normalized comparison matrix

Factor	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	Total	Average
C_1	0.0641	0.1017	0.0816	0.0916	0.1132	0.0471	0.0498	0.0659	0.0659	0.681	0.0756648
C_2	0.0214	0.0339	0.0204	0.0229	0.0566	0.0236	0.0299	0.0439	0.0439	0.297	0.0329427
C_3	0.0321	0.0678	0.0408	0.0458	0.0094	0.0314	0.0373	0.0527	0.0527	0.370	0.0411229
C_4	0.0321	0.0678	0.0408	0.0458	0.0849	0.0314	0.0373	0.0527	0.0527	0.446	0.0495086
C_5	0.0160	0.0170	0.1225	0.0153	0.0283	0.0188	0.0249	0.0377	0.0377	0.318	0.0353393
C_6	0.1283	0.1356	0.1225	0.1374	0.1415	0.0942	0.0746	0.0879	0.0879	1.010	0.1122095
C_7	0.1925	0.1695	0.1633	0.1832	0.1698	0.1884	0.1493	0.1318	0.1318	1.480	0.1643975
C_8	0.2567	0.2034	0.2041	0.2290	0.1981	0.2826	0.2985	0.2637	0.2637	2.200	0.2444073
C_9	0.2567	0.2034	0.2041	0.2290	0.1981	0.2826	0.2985	0.2637	0.2637	2.200	0.2444073
Total	1	1	1	1	1	1	1	1	1		

3.3.3 Consistency Analysis

Consistency analysis involves the calculation of the Consistency Ratio (CR), Consistency Index (CI) while the Random Index (RI) has already been generated by [22] as shown in Table 9. From the table, RI for this paper for N of nine (9) is 1.46.

Table 9: Random inconsistency indices for n = 10 [23]

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

N = order of Matrix

Equations (3), (4), (5) and (6) were used to calculate the consistency Vector, Consistency Measure, Consistency Index and Consistency Ratio. In order to calculate CI and CR, the matrix multiplication function was calculated using the EXCEL (=MMULT()) function where the averages and number of criteria serve as the arrays. Table 10 shows result for the process.

Table 10: Result of consistency analysis showing CR, CI and RI

	C_1	C_2	. . . . .	C_7	C_8	C_9	Total	Average	(MMULT)	N	Consistency Measure
C_1	0.06417	.	. . . .	.	.	.	0.68098	0.07566	0.869379118	9	9.869379118
C_2	0.02139		.	.	.	.	0.29648	0.03294	1.084848531	9	10.08484853

C_3	0.03209	.	.				.	.	.	0.37011	0.04112	1.079044658	9	10.07904466
C_4	0.03209	.	.				.	.	.	0.44558	0.04951	0.950148397	9	9.950148397
C_5	0.01604	.	.				.	.	.	0.31805	0.03534	0.938845846	9	9.938845846
C_6	0.12834	.	.				.	.	.	1.00989	0.11221	0.862793802	9	9.862793802
C_7	0.19251	.	.				.	.	.	1.47958	0.1644	0.924888443	9	9.924888443
C_8	0.25668	.	.	.	.	.	.	.	.	2.19967	0.24441	1.074079089	9	10.07407909
C_9	0.25668	.	.	.	.	.	.	.	.	2.19967	0.24441	1.074079089	9	10.07407909
Total	1	1					1	1	1			CI		0.123029264
												RI		1.46
												CR (CI/RI)		0.084266619

3.3.4 Criterion Weight (C_w)

From Table 10, the average of the column total is multiplied by the Consistency Ratio (CR) to get the required Criteria Weight (C_w) for the TOPSIS analysis. The result of this process is shown in Table 11.

Table 11: Analytic hierarchy process (AHP) distribution of weight

Criteria	Criteria Weight (C_w)
C_1	0.14590609
C_2	0.276207251
C_3	0.229392462
C_4	0.204424575
C_5	0.330824504
C_6	0.0994034
C_7	0.062731816
C_8	0.035512361
C_9	0.035512361

3.4 Decision Matrix

Having computed the weight function; the formulation of the attribute/alternative is shown in the following Matrix:

		Lagos VI	Koko (Warri)	Abonemma (Rivers)	Criteria Weight
C_1	Power Demand	4.5	3.875	4.375	0.14590609
C_2	Distance from Airport	533	438.5	448.23	0.276207251
C_3	Average Wind Speed	6.25	7.29	7.35	0.229392462
C_4	Shipping Route	1.75	3.875	4.375	0.204424575
C_5	Undersea Gas Line	2.375	4.5	4.875	0.330824504
C_6	Distance from Shore	500	350	400	0.0994034
C_7	Distance from Disco	531.125	431.85	426.875	0.062731816
C_8	Bird Flight Interference	2.25	2.5	3.25	0.035512361
C_9	Telecom Interference	3.25	4.625	4.125	0.035512361

Due to great disparity in the type of data, the matrix is resolved into two separate parts using Microsoft Excel. Figure 5and Figure 6 show the charts of the quantitative and qualitative attributes for the three alternatives.

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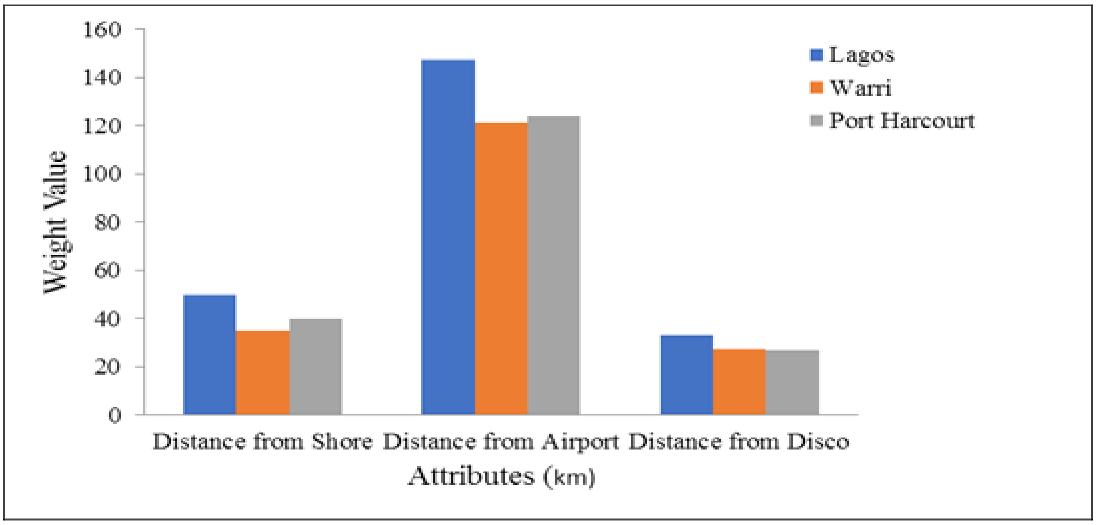

Figure 5: Chart of quantitative attributes value for three alternatives

From Figure 5, Lagos has the highest distance from shore and that brings it close to the ideal positive solution as offshore wind farms are expected to be at least 50km away from shores for impaired visibility and noise. Koko (Warri) and Abonemma (Rivers) are far from the Ideal Positive Solution and that shows they are closer to the Ideal Negative solution. In terms of distance from airport, the ideal positive solution will be the location with the farthest distance from airports so as to avoid flight interference. From the bar chart, Lagos VI is also found to be the closest to an ideal positive solution while the other alternatives are on the side of the ideal negative solution. However, looking at the distance from distribution company, Lagos VI regardless of the highest value, is not close to the ideal positive solution but to the ideal negative solution as the positive solution in this case will be a location closest to a distribution company so as to easily connect to the national grid. Therefore, Koko (Warri) is the closest to the ideal positive solution followed closely by Abonemma (Rivers).

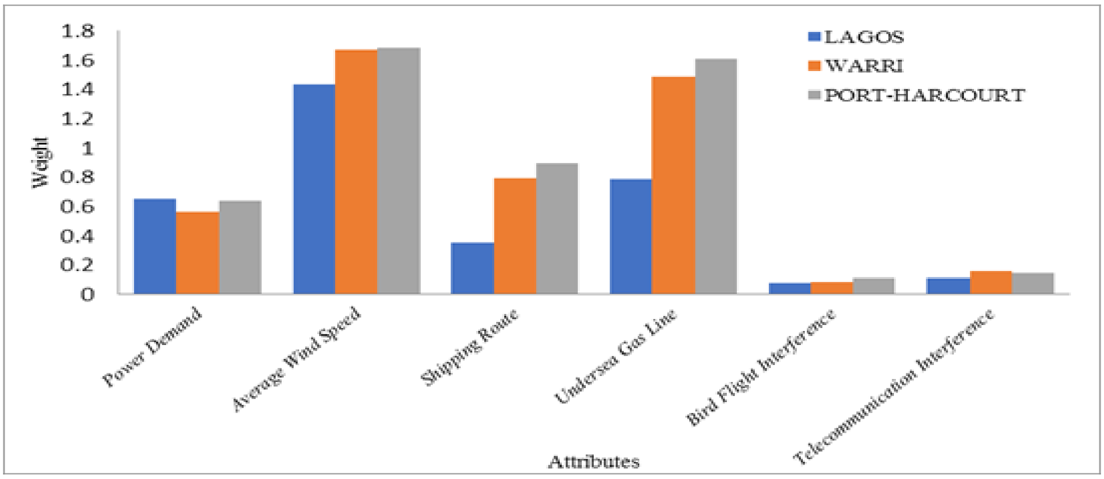

Figure 6: Chart of qualitative attributes value for three alternatives

Results of qualitative analysis displayed in Figure 6 shows that Lagos VI has the highest demand for electricity; followed closely by Abonemma (Rivers) while Koko (Warri) is lowest in terms of electricity demand. This result may be attributed to some factors which are; the level of industrialization, the land mass area of the location and its relative population. Bird flight was found to be very minimal in Lagos VI, followed by Koko (Warri) and highest in Abonemma (Rivers). Although from literature [14], much attention was not given to interference with bird flight. The explanation given in [14] was that it was observed that birds often move away from the premises of wind farms after the turbines are installed. Another possible explanation may be due to the noise from the turbines when they in operation. High value for shipping route indicates an ideal negative solution and from the result presented on the bar chart, Abonemma (Rivers) was found the closest to the ideal negative solution while Lagos VI is the closest to the ideal positive solution.

Abonemma (Rivers) was also found to have the highest value for undersea gas and cable lines followed by Koko (Warri) while Lagos VI has the least. The ideal positive solution for this attribute will be a location with the least value as this enables easy construction of windfarm turbine foundations. Therefore, Lagos VI is the closest to the ideal positive solution.

Lastly, for telecommunication installations in the three alternatives, a low value here indicates a Positive ideal solution and Lagos VI has the least value and this implies that it is the closest to the positive ideal situation.

3.5 Normalized Data

The qualitative and quantitative attributes can be combined by normalizing the data. The normalization process takes care of the disparity in data. This was done using Equations (8) and (9). The Normalization was done as well on Microsoft Excel using equations and the result is shown in Table 12 while the chart of the normalized results of the three attributes is shown in Figure 7.

Table 12: Normalized attribute values for the three alternatives

Attributes	Alternatives		
	Lagos VI	Koko (Warri)	Abonemma (Rivers)
Power Demand	-0.51669886	-0.50940128	-0.515217729
Distance from Airport	2.475748931	2.515977327	2.495524571
Average Wind Speed	-0.50083179	-0.48162274	-0.489607252
Shipping Route	-0.52280035	-0.50371051	-0.508959467
Undersea Gas Line	-0.51406231	-0.48622941	-0.491398187
Distance from Shore	0.48468654	0.349534551	0.441128166
Distance from Disco	0.150179123	0.156282669	0.123771098
Bird Flight Interference	-0.52847318	-0.52136223	-0.528000387
Telecommunication Interference	-0.52774811	-0.51946838	-0.527240813

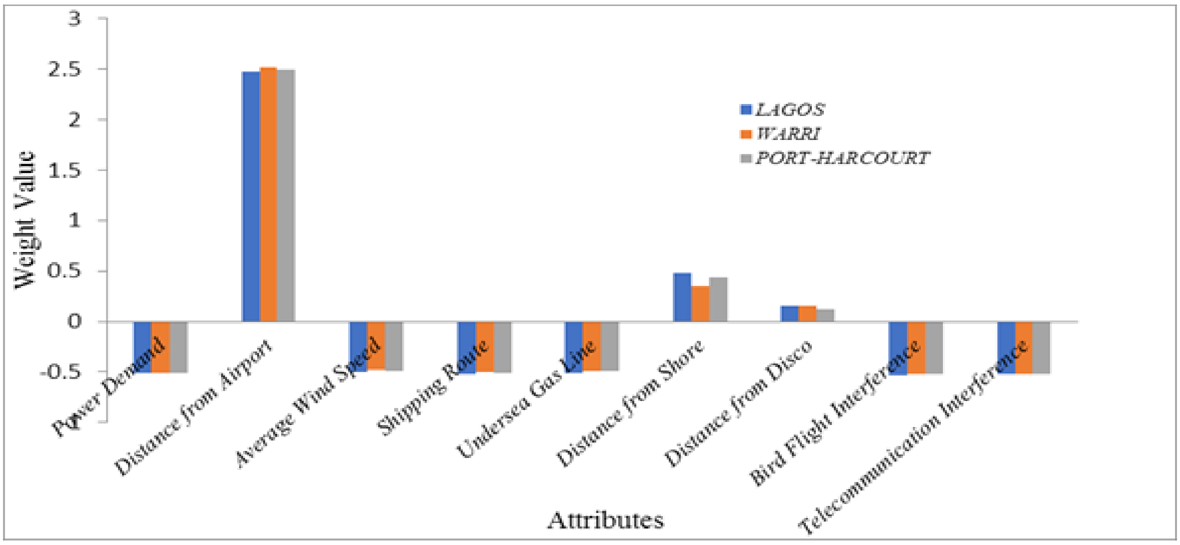

Figure 7: Bar chart of the normalized attributes value for three alternatives

To make a final selection of which alternative amongst the three locations analysed is best for consideration for the installation of offshore wind farm, cumulative of all the attributes value were calculated for the three alternatives. The cumulative value is shown on Table 13 while Figure 8 gives the graphical representation.

Table 13: Alternatives Cumulative Result

Alternatives	Lagos VI	Koko (Warri)	Abonemma (Rivers)
Cumulative	233.67	187.77	195.44

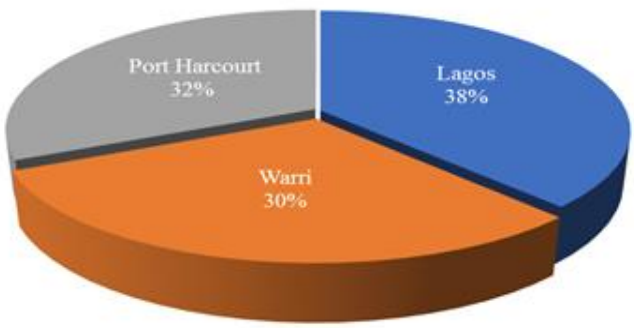

Figure 8: Cumulate Decision Pie Chart

Figure 8 shows that Lagos has the highest consideration rate of 38% followed by Port-Harcourt with 32% and lastly Warri with 30%.

4. CONCLUSION

Multi-Criteria evaluation procedure was applied to evaluate the viability of three offshore locations in Nigeria as potential sites for windfarms. Attributes for the locations; Victoria Island (Lagos), Koko (Warri) and Abonnema (Port-Harcourt) were evaluated using multi-criteria analysis tool (TOPSIS), which has shown to be a reliable method. The outcome of the study showed that the three locations present good wind profile. This was shown by the 10-years average wind speeds, which were 6.25m/s, 7.29m/s and 7.347m/s for Victoria Island, Koko (Warri) and Abonnema (Port-Harcourt) respectively. The application of analytical hierarchy process (AHP) gave a normalized column total of 1, consistency index of 0.123029264 and consistency Ratio of 0.084266619 which is in accordance with Saaty[22] recommendations. The TOPSIS gave the highest consideration rate for Victoria Island; which may therefore be considered as the best location for the installation of offshore wind farm facilities.

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