IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Multi-Criteria Evaluation of the Appropriate Offshore Wind Farm Location in Nigeria

IOP Conf. Series: Materials Science and Engineering **413** (2018) 012041 doi:10.1088/1757-899X/413/1/012041

Multi-Criteria Evaluation of the Appropriate Offshore Wind Farm Location in Nigeria

E. A. Mayaki*, O. Adedipe and S A. Lawal

School of Infrastructure, Process Engineering and Technology, Federal University of Technology Minna, Nigeria
Corresponding author's email: mayakionimisi@gmail.com

Abstract - This paper presents a multi-criteria evaluation of the appropriate offshore wind farm location in Nigeria. The proposed site selection criterion takes into consideration the technical aspect of the Environment consideration. The four attributes considered in this work are proximity to power demand, Distance from Airport, Average wind speed and Interference with existing shipping route. These attributes were analyzed for three alternative locations (Victoria Island, Koko and Abbonema in Lagos, Warri and Port-Harcourt respectively) using Analytical Hierarchy Process to assign weight through pair-wise comparison and fuzzy TOPSIS Multi-criteria decision-making tool to make an appropriate selection. The results from this work showed that Victoria Island (Lagos) has the highest figure cumulative value of 894.23, Koko (Warri) has 740.04 and Abonnema (Port-Harcourt) with a value of 756.96.

1. Introduction

Energy provides an essential ingredient for almost all human activities: such as cooking and space/water heating, lighting, healthcare, food production and storage, education, mineral extraction, industrial production and transportation [1]. Nigeria's energy is supplied from different hydro-power and thermal power stations. The extent of water available at these different hydro-power stations varies due to change in seasonality and this causes irregular supply at low water levels periods. The thermal power stations are also affected by lack of adequate supplies of natural gas [2]. The solution for the country is energy diversification. Harnessing offshore wind power was talked about as early as the 1930s, not until 1990, when the first modern offshore wind turbine was constructed 250 m offshore of Northern Sweden [3]. According to Okokpujie et al [4] and Odia et al. [5] the authors stated that wind turbine will serve as one of the major way to resolve the issue of energy supply in Nigeria. Multiple-criteria decision 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) [6]. Conflicting criteria are typical in evaluating options: cost or price is usually one of the main criteria, and some measure of quality is typically another criterion, easily in conflict with the cost. There have been important advances in this field since the start of the modern multiple-criteria decision-making discipline in the early 1960s [7]. The MCDM problem can be represented in the criterion space or the decision space. Alternatively, if different criteria are combined by a weighted linear function, it is also possible to represent the problem in the weight space. The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then. It has particular application in group decision making [8] and is used around the world in a wide variety of decision situations, in fields such as government, business, industry, healthcare, ship building and education, [9]. Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to each other two at a time, with respect to their impact on an element above them in the hierarchy. In making the comparisons, the decision makers can use concrete data about the elements, but they typically use their judgments about the elements' relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations [9]. The

AHP converts these evaluations to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way [10].

2. Data Collection

This study is limited to technical attribute required for the location of a wind farm. The considered data are Power Demand, Distance from Airport, Average wind speed and Shipping route. These data were collected for the three states i.e. Lagos, Warri and Port-Harcourt, which are the alternatives for which their attributes were analysed. The required Average Wind Speed was collected from the Nigerian Meteorological Agency (NIMET), while the quantitative attributes were sourced for and qualitative attributes were obtained using Questionnaires.

Table 1 Ten years' average wind speed for Lagos Warri and Port-Harcourt

Alternatives	Years										Average
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	
Lagos	7.21	6.49	7.27	7.32	7.21	7.6	5.88	4.83	4.7	4	6.251
Warri	7.38	7.46	7.35	7.32	7.32	7.17	7.48	7.07	7.2	7.19	7.294
Port harcourt	7.3	7.37	6.89	7.13	7.38	7.06	7.54	7.3	7.56	7.94	7.347

Table 2 Attributes Value for the three Alternatives

Attributes	Alternatives		
	Lagos	Warri	Port-Harcourt
Power Demand	4.5	3.875	4.375
Distance from Airport	533	438.5	448.23
Average Wind Speed	6.25	7.29	7.35
Shipping Route	1.75	3.875	4.375

3. Multi-criteria Evaluation Process

The pair-wise element matrix is the first step to the application of Analytical Hierarchy Process: The matrix if formed by comparing one criterion against another. Two criteria with same level of importance will have a score of 1, a criterion that is more important than that which it's been compared with will have its actual value on the Effective Criteria and Pair Wise Comparison while a criterion less important than that which it is been compared to will be score the inverse of its actual value on the Effective Criteria and Pair Wise Comparison as shown in Table 2.

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

Having completed the comparison matrix next is to normalize the matrix: The sum of the pair-wise criteria matrix column was calculated. Each entry in the column is then divided by the column sum to yield its normalized score, the sum of each column of the normalized matrix. These procedures are done with the equations (1) and (2).

$$C_{ij} = \sum_{i=1}^{n} c_{ij} \tag{1}$$

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

Consistency Analysis

Consistency analysis involves the calculation of the Consistency Ratio (CR), Consistency Index (CI): while the Random Index has already been generated by Satty, 2008 as

Table 3 Random inconsistency indices for n = 10

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

Notes: n = order of Matrix

To calculate the CI and CR the Matrix Multiplication Function was calculated using the EXCEL (=MMULT()) function.

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

$$Average(\mu) = \frac{\sum_{i=1}^{n} C_{ij}}{n} \quad (4)$$

$$\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (C_{ij} - \mu)^2} \quad (5)$$

Below are the results for the Multi- criteria analysis of four (4) criteria for a 3 alternatives. Rating scale is as shown in Table 1.

Table 4 Effective Criteria and Pair Wise Comparison

Factor	Factor weighting Score											Factor
	More Important than					Equal	Less Important than					
C1	1	2	3	4	5	1	1	2	3	4	5	C2
C2	1	2	3	4	5	1	1	2	3	4	5	C3
C3	1	2	3	4	5	1	1	2	3	4	5	C4
C4	1	2	3	4	5	1	1	2	3	4	5	C1

IOP Conf. Series: Materials Science and Engineering **413** (2018) 012041 doi:10.1088/1757-899X/413/1/012041

Table 5 Pair Wise Comparison Matrix

Factor	C1	C2	C3	C4
C1	1	3	2	2
C2	0.3333	1	0.5	0.5
C3	0.5	2	1	1
C4	0.5	2	1	1

Table 6 Column Total For Pair Wise Comparison Matrix

Factor	**C1**	**C2**	**C3**	**C4**
C1	1	3	2	2
C2	0.3333	1	0.5	0.5
C3	0.5	2	1	1
C4	0.5	2	1	1
Total	2.3333	8	4.5	4.5

Table 7 Row Total For Normalized Pair Wise Comparison Matrix

Factor	C1	C2	C3	C4	Total	Average
C1	0.4285776	0.375	0.4444444	0.4444444	1.6924664	0.4231166
C2	0.1428449	0.125	0.1111111	0.1111111	0.4900671	0.1225168
C3	0.2142888	0.25	0.2222222	0.2222222	0.9087332	0.2271833
C4	0.2142888	0.25	0.2222222	0.2222222	0.9087332	0.2271833
Total	1	1	1	1		

Table 8 Consistency Analysis For Normalized Pair Wise Comparison Matrix

Factor	C1	C2	C3	C4	Total	Average	Consistency Measure
C1	0.4285776	0.375	0.4444444	0.4444444	1.6924664	0.4231166	5.014431
C2	0.1428449	0.125	0.1111111	0.1111111	0.4900671	0.1225168	5.030388
C3	0.2142888	0.25	0.2222222	0.2222222	0.9087332	0.2271833	4.0978367
C4	0.2142888	0.25	0.2222222	0.2222222	0.9087332	0.2271833	4.0978367
Total	1	1	1	1		CI	0.186708
						RI	0.9
						CR (CI/RI)	0.207453

Table 9 Criteria Weight from AHP analysis

Citeria	C1	C2	C3	C4
Weight	0.48405	1.659624	0.933539	0.933539

Table 10 Decision Matrix

		Lagos	Warri	Port-Harcourt	Criteria Weight
C1	Power Demand	4.5	3.875	4.375	0.48405
C2	Distance from Airport	533	438.5	448.23	1.659624
C3	Average Wind Speed	6.25	7.29	7.35	0.933539
C4	Shipping Route	1.75	3.875	4.375	0.933539

Table 11 Result of Decision Matrix analysis

Attributes	Alternatives		
	Lagos	Warri	Port-Harcourt

Power Demand	2.178225	1.875694	2.11771875
Distance from Airport	884.5796	727.7451	743.8932655
Average Wind Speed	5.834619	6.805499	6.86151165
Shipping Route	1.633693	3.617464	4.084233125
Total	894.226	740.044	756.95673

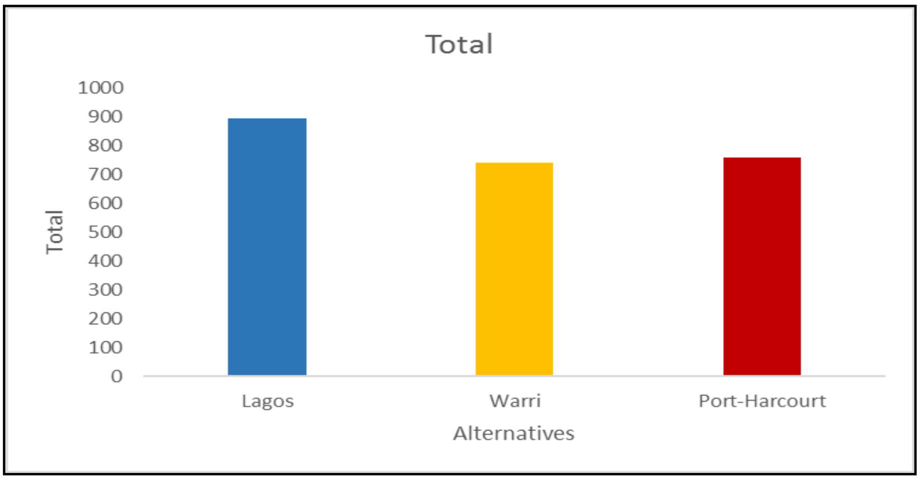

Figure 1 Bar chart of the cumulative result for the three alternatives

4. Conclusions

Nigeria has a great potential for offshore wind farm projects and this should be considered to solve the issue epileptic power supply in the country and the Analytic Hierarchy Process and fuzzy TOPSIS are applicable for the multi-criteria selection of the appropriate offshore wind farm location in Nigeria. The collected wind farm siting attributes revealed that the three alternatives showed a good wind speed characteristic and this was shown by the 10 years' average wind speeds collected for three locations. The application of Analytic Hierarchy Process gave a normalized column total of 1, consistency index and consistency ratio within the expected range as stated by Satty, [10] and finally from the multi-criteria analysis, Victoria Island was found to show the highest consideration value.

References

[1] Gelbspan, R. (2004), Towards a global energy transition. Foreign Policy in Focus: FPIF – PetroPolitics Special Report. www.petropolitics.org

[2] Iwayemi, A., Nigeria's dual energy problems: Policy issues and challenges, International Association for energy economics, Fourth Quarter, 2008, available online [www.iaee.org/en/publications/newsletterdl.aspx? id=53, accessed 21 December 2009], 17–21

[3] Bilgili, M., A. Yasar & E. Simsek (2011) Offshore wind power development in Europe and its comparison with onshore counterpart. Renewable and Sustainable Energy Reviews, 15, 905-915.

[4] Okokpujie, I. P., Okokpujie, K. O., Nwoke, O. N., & Azeta, J. DEVELOPMENT OF A 0.5 KW HORIZONTAL AXIS WIND TURBINE. *Journal of Engineering and Applied Sciences*, *13*(8), 2202-2208.

[5] Odia, O. O., Ososomi, S. A., & Okokpujie, P. I. (2016). Practical Analysis of A Small Wind Turbine for Domestic Use on Latitude 7.0670 N, Longitude 6.2670 E. *Journal of Research in Mechanical Engineering*, *2*(11), 8-10.

[6] Weistroffer, H. R., Smith, C. H., and Narula, S. C., "Multiple criteria decision support software", Ch 24 in: Figueira, J., Greco, S., and Ehrgott, M., eds, Multiple Criteria Decision Analysis: State of the Art Surveys Series, Springer: New York, 2005

[7] *Mardani, Abbas; Jusoh, Ahmad; Zavadskas, Edmundas Kazimieras (2015-05-15).* "Fuzzy multiple criteria decision-making techniques and applications – Two decades review from 1994 to 2014". *Expert Systems with Applications. 42 (8): 4126–4148.* doi*:*10.1016/j.eswa.2015.01.003
[8] Kao, C. (2010). Weight determination for consistently ranking alternatives in multiple criteria decision analysis. Applied Mathematical Modeling, 34, 1779–1787
[9] Pohekar SD, Ramachandran M (2004) Application of multi-criteria decision-making to sustainable energy planning–a review. Renew Sustain Energy Rev 8:365–381
[10] Saaty, T.L. (2008) 'Decision making with the analytic hierarchy process', *Int. J. Services Sciences*, Vol. 1, No. 1, pp.83–98.