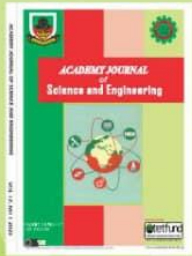

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Original Research

ECONOMIC ANALYSIS OF WIND FARM FEASIBILITY IN NIGERIAN DEFENCE ACADEMY, AFAKA, KADUNA

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Abstract

The challenge of providing adequate amount of energy is a global issue. Adopting renewable energy for electricity production is a notable objective, several countries have since began the process of harnessing and developing wind energy into electricity. A modern wind turbine is a device that converts wind energy into electricity and wind farm (wind power plant) is an assembly of wind turbines that are site operated for the generation of electrical energy. In order to achieve energy usage capacity (5MW) in Nigerian Defence Academy permanent site Afaka Kaduna there is need for wind farm. Several related literatures were reviewed and based on the reviewed few studies have been conducted using Afaka Kaduna wind speed, the studies were done on the economic analysis only evaluated the levelized cost of electricity. In order to completely described the economic feasibility of a study, net present value (NPV), internal rate of return (IRR) and payback period needs to be determined. This study carried out the feasibility analysis of a wind farm in Nigerian Defence Academy permanent site Afaka, Kaduna. Twelve years daily wind speed data ranging from 2009-2020 was obtained from Nigeria Meteorological Agency (NiMet) to analyzed the wind profile of the study site. The method employed was Weibull 2-parameter probability distribution function for the analysis of the site wind profile and Microsoft excel for the analysis of the net present value (NPV), internal rate of return (IRR) and payback period (PBP). The raw wind speed obtained was analyzed to have a minimum and maximum average annual wind speed values of 5.6m/s and 9.5m/s in 2014 and 2020 respectively. From the Weibull analyses the standard deviation, shape factor (k), scale factor c, power density, theoretical energy and extractable energy were found to be 0.92, 22.84, 9.26m/s, 529.33W/m², 293.83W/m² and 495.50W/m² respectively. The cost analysis for a selected wind turbine from E40 ENERCON Manufacturer with specification that fits the purposed study site was 114, 216,087 NGN. The total cost of the proposed 5MW capacity power plant with ten wind turbines was 1, 142, 160, 870 NGN. The result revealed at 10% interest rate the net present value (NPV), internal rate of return (IRR) and payback period (PBP) were 174,337,863.19 NGN, -84.74% and 10 years respectively. The cost of kilowatt hour was estimated to be #48 which is moderately better than what is obtainable. Hence, the analysis of the study area can be used for establishment of wind farm.

Keywords: E40 ENERCON Wind turbine, Internal Rate Return, levelized Cost, Net Present Value, Payback Period, Wind energy

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1.0 INTRODUCTION

Due to worldwide technological improvement and population growth, energy has become a crucial unit for survival and progress of man the global village. Nevertheless, some emerging countries around the world are experiencing shortages as a result of rising energy demand and exponential expansion in both human and industrial sectors. Fossil fuels or conventional energy resources are currently the primary sources of power in most parts of the world. However, subsequent examinations have revealed rapid depletion as a result ofexcessive demand. The use of these (fossil) fuels has major environmental and health consequences, necessitating the adoption of (alternative) renewables in future energy mix in the Nigeria[1].

Renewables accounted for around 23.7 percent of worldwide electricity generation at the end of 2015, with hydropower accounting for 16.6 percent. Though there are considerable renewable energy (RE) potentials around the world and the share of renewables in global power production is increasing, their contribution is still negligible when compared to traditional sources. Currently, most renewable energy additions differ per country, owing to rising electricity demand. Wind technologies account for only about 3.7 percent of global electricity output among these renewable sources [2].

Without a question, an adequate supply of power at a reasonable price is one of humanity's most basic demands. The delivering of appropriate and sufficient power to the people is currently still a world wide issue. The level of concern may differ from developed to developing countries, but providing consistent power is a major issue all over the world. As a result, all efforts must be made to find ways to meet the expanding energy demand of the world population. These energy sources are naturally occurring, and the formation takes a long gestation period to complete. Because of this aspect these resources are considered non-renewable and finite. Furthermore, inability of governments incapacity to provide adequate and reliable energy or electricity for the people is responsible for social and economic poverty and the attendant consequences [3].

Most countries throughout the world have begun to harness and develop alternate energy resources. Furthermore, the vast majority of these resources are plentiful and are found to be environmentally beneficial; for example, wind, which is almost free, has long been used by nations around the world to develop and expand their energy capacities. China, the United States of America, Germany, Canada, the United Kingdom, France, Spain, and India are notable countries in this quest, having installed wind power capacity in the Gigawatt range [4].

Africa's overall area, including nearby islands, is around 30.2 million km (11.7 million square miles). This accounts for 6% of the planet's total surface area and 20.4 percent of its land area. Africa is the second-largest and most populous continent on the planet. However, it is at the rock bottom of the ladder in terms of energy generation and delivery as it only meets, just 20% of the required demand. There is no doubt in the claim that Africa's oil reserves have increased by 25% and its gas reserves by 100% in the last 20 years. The Congo's enormous Inga River has the potential to supply more than half of Africa's electricity needs. Africa's wind resources are never in short supply. Their benefits were also emphasized by the Program for Infrastructure Development in Africa (PIDA), which emphasizes the need for energy infrastructure through energy sector deregulation [5].

Despite these enormous resources, most African countries have been unable to fully meet their people's energy needs. The majority of African countries are afflicted by an energy crisis, which is mostly caused by generation and transmission issues caused by poor infrastructure and carelessness. Even wind and solar power generating are severely underdeveloped in most African countries. South Africa, Morocco, Egypt, Ethiopia, and Kenya are the five African markets that are leading the way in wind power generation. [6,7,8,9,10]

The difficulties in developing wind energy projects in West Africa may, however, be due to a lack of data on the region's wind energy potential. This is largely due to the fact that wind resources are site specific, hence an assessment of as many locations as feasible is required to appropriately identify a country's wind energy potentials. [5,7]

For decades, wind energy has been used in Nigeria to power water pumps, mostly in the agriculture sector [2]. In recent years, most of the focus has been on using it to create power, and there are still technical challenges with integrating what may be generated into the national grid [6].

Wind energy technologies have been tested in the northern regions of the country over the years, mostly for water pumping from open wells in several secondary schools in ancient Sokoto and Kano States, as well as Katsina, Bauchi, and Plateau States [2].

Green electricity (which is electricity produced from renewable sources that is ecologically benign and non-polluting) production for the rural community and its integration into the national grid are two more "possible applications" areas of wind energy resources in Nigeria [3].

Wind patterns in Nigeria are primarily from the east for interior areas and from the west for coastal locations. Strong winds cover the country during the harmattan period (December – March), especially in the northern areas where the major wind direction is from the north-east. [11]

Many studies on wind resource evaluation have been conducted around the world to estimate the potential of various locations for local wind power/electricity production [12,13,14]. Many studies in Nigeria have also been carried out on wind resource evaluation. Each of these investigations looked at distinct sites, and the current analysis back up their findings. According to the Nigeria Development Programme's Energy Commission, considerable variances in distribution exist within the same localities due to the country's diverse topography and terrain roughness. The fact that wind resources are site specific backs this up[15].

A wind energy system might be considered for profitability. To estimate this, it is necessary to compare the wind energy project with other investments and an economic analysis carried out [16.17]. The three key components of the cost of generating energy in a wind farm are capital, operations and maintenance and finance costs. The lack of fuel expenditures distinguishes renewable energy sources such as wind from the counterpart fossil fuel. The cost of producing unit power changes only slightly once the wind farm is established. As a result, wind energy's economics are heavily reliant on capital costs. A cost-effective solution is the best-suited alternative, both technically and economically. Few studies have been conducted using Kaduna wind speed for the case study. These studies considering the economic analysis only evaluated the levelized cost of electricity. In order to completely describe the economic feasibility of a study, net present value (NPV), internal rate of return and payback period needs to be determined.

Therefore, this article has investigated the economic analysis of a wind farm feasibility in the vicinity of the Nigerian Defence

Academy, which is located in the Igabi Local Government Area in Kaduna state. The institution is located between the Greenwich meridian's longitudes of 7° 12'E and 7° 35'E and the equator's latitudes of 10° 36'N and 10° 42'N[18].

2.0 MATERIALS AND METHODS

Material

Data Collection

Daily wind speed data for Afaka-NDA Kaduna was collected from the Nigeria Meteorological Agency (NiMet) for a period of twelve (12) years and Microsoft excel software was used for the evaluation of the data.

Method

The Weibull 2-parameter probability distribution function has proven to be quite adaptable for determining the wind profile of a location [19]. It is still considered the greatest in terms of quality and application variety. As a result, the approach was used in this investigation.

(i)The probability density function is given as:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad \ldots\ldots(1)$$

Where, $f(v)$ = Weibull distribution function, F_W= Weibull cumulative distribution function, v= wind speed, k= the Weibull shape parameter (dimensionless), c= the Weibull scale parameter (in meter per second) [19].

(ii) The Weibull shape factor (k), Weibull scale factor (c), and standard deviation parameters are all used to calculate the Weibull shape factor.

$$k = \left[\frac{\sigma}{V_m}\right]^{-1.086} \quad \ldots\ldots(2)$$

Weibull scale factor (c) is given by [19];

$$c = \frac{V_m}{\Gamma\left(1+\frac{1}{k}\right)} \quad \ldots\ldots(3)$$

Where σ is the standard deviation, v_m is the average wind speed (m/s), $\Gamma(x)$ is the gamma function of (x).

$$V_m = \frac{1}{n}\sum_{i=1}^{n} V_I \quad \ldots\ldots(4)$$

The standard deviation is given by: $$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(V_i - V_m)^2} \quad \ldots\ldots(5)$$

Where σ is the standard deviation, v_m is the average wind speed (m/s) [19].

(iii) The Wind Power Densityis a measure of how powerful the wind is.There are two types of Wind Power Density (WPD). The first is based on available wind power as measured by the conversion system and computed directly from wind speed v (m/s), while the second is based on the Weibull two-parameter method. The following are the two approaches: [20]:

$$P(v) = 1/2AV^3 \quad \ldots\ldots(6)$$

$$p(v) = (v) = \tfrac{1}{2}\rho c^3(1+(3/k)) \quad \ldots\ldots(7)$$

Where, *P(v)* is the wind power (W), *p(v)* is the wind power density (W/m²) and ρ is the air density (kg/m³) at the sites [20].

(iv) Potential of Wind Energy

The available energy per unit area perpendicular to the wind stream during a particular period of time t is expressed by kinetic energy [20] as:

$$Ea = 0.5\rho V^3 \text{……………………} (8)$$

Where ρ is the air density in kilograms per cubic meter, and Ea denotes the theoretical total energy available to operate the turbine. Only a small portion of the total energy would be retrieved, though. A coefficient of performance known as the Beltz limit (16/27 = 0.593) limits the maximum extractable energy from a system operating at itshighest efficiency. [19], [20] gives

$$EM = 0.2965\rho V^3 \text{………………………………………………………….} (9)$$

as the capacity factor, which makes the extractable energy approximately 59.3% of the theoretical energy.

Economic Analysis

i. **Cost Analysis**

The annual extractable energy at the site (Watt), capital cost of a turbine, installation cost, importation cost, incidental cost, and tariff per kilowatt per hour for conventional power must all be understood in order to compute the total initial cost of the wind turbine.

Therefore, the total initial cost per turbine is calculated as follows:

Capital cost + Installation cost + Other cost ……………………………………………(10)

ii. **Net Present Value (NPV), Internal Rate Return (IRR) and Payback Period (PBP).**

The key economic criteria are net present value (NPV), internal rate of return (IRR), and payback period (PBP) [21]. Projects in the energy distribution industry have a long lifespan. Wind farms, on the other hand, have a 25-year lifespan. As a result, for capital-intensive long-term projects such as wind farms, the time value of money becomes extremely important. NPV is a powerful predictor of project feasibility [21] and is calculated using the following relationship:

NPV=Σ(B-C)/(1+r) ˆn………………………………………………………………………(11)

Where NPV is the net present value, B the benefit, C the cost, n is the period and r the discount rate. The greater the NPV of a project, the more profitable it is [21]. IRR is also a popular and widely used method in financial analysis to evaluate the profitability of potential investments. The IRR is discount rate "r" which equates two streams of costs and benefits [22]. Alternatively, it is the rate, which would make NPV value equal to zero and is given by: -

Σ[C/(1+r) n] =Σ[B/(1+r) ^n] ……………………………………………………………(12)

A common and simple way to evaluate the economic merit of an investment is to calculate its Pay Back Period or break-even period. The payback period is the number of years of energy-cost savings it takes to recover an investment's initial cost [23].

It is given by: -

Payback time in years = Total initial cost / (Annual Energy cost savings) – (Annual maintenance Cost (1

iii. The Levelized Cost of Electricity (LCOE)

The real cost of producing kilowatt-hours (kWh) of energy is known as the LCOE. It is one of the most essential measures for assessing the fiscal performance of the wind energy conversion system (WECS) power supply. The Levelized Cost of Electricity (LCOE) is a cost-effectiveness metric used to compare the cost-effectiveness of various energy sources [24].

LCOE is given by: -Levelized Cost of Electricity = Total Initial of turbine/Annual extractable energy……………..(14)

The current study employed the above factors to analyze the economic feasibility of a wind farm on the permanent site of the Nigerian Defence Academy in Afaka, Kaduna and E40 ENERCON manufacturer turbine cost sample was used[25].

3.0. RESULTS AND DISCUSSION

Data Analysis

(i) Wind Profile

The result of the wind profile was evaluated using equations (1-9). The average annual minimum and maximum variation for the whole period considered of the wind speed, scale factor, power density, theoretical power and extractable energy ranged at 5.6m/s, 4.80, 66.31W/m², 108.63W/m², 64.42W/m² in 2014 and 9.5m/s, 9.26, 529.33W/m², 495.50W/m², 302.42W/m² in 2010 respectively. The average annual minimum and maximum shape factor (k) was 480.98 and 22.84 in 2015 and 2020 respectively. The average annual minimum and maximum standard deviation was 0.19m/s and 0.92m/s in 2019 and 2020 respectively.

Economic Analysis

(ii) Cost Analysis and Payback Period

The cost analysis and payback period were evaluated by equations 10 and 13 respectively and results are presented on table 1.

Table 1: Cost Analysis of the wind turbine

S/No	Item	
1	Watt	271.9804 KW
2	kWh per annum (Watt * 24hrs * 365 days)	2.382548.394 MW
3	Tariff per kilo-watt	62.80 NGN
4	Annual Energy Cost (tariff per watt * kWh per annum/1000)	149,624,033.49 NGN
5	Suitable Turbine from E40 ENERCON manufacturer	500-800 kilowatt
6	Capital Cost of Turbine	191,445 Dollars equivalent to 72,749, 100 NGN (380NGN per dollar)
7	Installation Cost (30% of Capital Cost)	21,824,730 NGN
8	Importation Cost (20% of Capital Cost)	14,549,820 NGN
9	Maintenance Cost (5% of Capital Cost)	3,637,455 NGN
10	Miscellaneous (2% of Capital Cost)	1,454,982 NGN
11	Total Initial Cost per turbine	114, 216,087 NGN
12	Total cost of the proposed 5MW power capacity (ten wind turbines)	1, 142, 160, 870 NGN
13	Total Maintenance Cost	36,374,550 NGN
14	Pay Back Period	= 10 years

(iii) Results of Net Present Value and Internal Rate of Return

The results of the Net Present Value and Interest Rate of Return were obtained using equations (11) and (12) and the results are presented in the table

Table 2: Results of Net Present Value and Internal Rate of Return

Decision Horizon (T) = 25yrs.		Interest rate, r = 0%	Interest rate, r =10%

Yr	Total Initial Cost	Operating Cost	Revenue	Annual Cash Flow	Discounted Cash Flow	Cumulative NPV	Discounted Cash Flow	Cumulative NPV
0	1142160870			1142160870	1142160870	1142160870	1142160870	1142160870
1		36374550	149624033.49	113249483.4	113249483.4	1028911386.6	102954075.8	1039206794.2
2		36374550	149624033.49	113249483.4	113249483.4	915661903.2	93594614.38	1029847179.8
3		36374550	149624033.49	113249483.4	113249483.4	802412419.8	85086013.07	944761166.73
4		36374550	149624033.49	113249483.4	113249483.4	689162936.4	77350920.98	867410245.75
5		36374550	149624033.49	113249483.4	113249483.4	575913453	70319019.07	797091226.68
6		36374550	149624033.49	113249483.4	113249483.4	462663969.6	63926380.97	733164845.71
7		36374550	149624033.49	113249483.4	113249483.4	349414486.2	58114891.79	675049953.92
8		36374550	149624033.49	113249483.4	113249483.4	236165002.8	52831719.81	622218234.11
9		36374550	149624033.49	113249483.4	113249483.4	122915519.4	48028836.19	574189397.92
10		36374550	149624033.49	113249483.4	113249483.4	9666036	43662578.36	530526819.56
11		36374550	149624033.49	113249483.4	113249483.4	1013583447.4	358642701.6	171884117.96
12		36374550	149624033.49	113249483.4	113249483.4	216832930.8	253869268.6	81985150.64
13		36374550	149624033.49	113249483.4	113249483.4	330082414.2	32804341.36	49180809.28
14		36374550	149624033.49	113249483.4	113249483.4	443331897.6	29822128.51	19358680.77
15		36374550	149624033.49	113249483.4	113249483.4	556581381	27111025.92	7752345.15
16		36374550	149624033.49	113249483.4	113249483.4	669830864.4	24646387.2	32398732.35
17		36374550	149624033.49	113249483.4	113249483.4	783080347.8	22405806.55	54804538.9
18		36374550	149624033.49	113249483.4	113249483.4	896329831.2	20368915.04	75173453.94
19		36374550	149624033.49	113249483.4	113249483.4	1009579314	18517195.39	93690649.33
20		36374550	149624033.49	113249483.4	113249483.4	1122828798	16833814.17	110524463.5
21		36374550	149624033.49	113249483.4	113249483.4	1236078281	15303467.3	125827930.8
22		36374550	149624033.49	113249483.4	113249483.4	1349327764	13912243	139740173.8
23		36374550	149624033.49	113249483.4	113249483.4	1462577248	12647493.74	152387667.54
24		36374550	149624033.49	113249483.4	113249483.4	1575826731	11497721.48	163885389.02
25		36374550	149624033.49	113249483.4	113249483.4	1689076215	10452474.17	174337863.19

NET PRESENT VALUE NPV	1689076215	174337863.19
NPV using PV function	1689076215	174337863.19
NPV using NPV function	1689076215	174337863.19
INTERNAL RATE OF RETURN IRR	33.38%	-84.74%

(iv) Levelized Cost of Electricity

For the results of the levelized cost of electricity was calculated using equation (14)

. Levelized Cost of Electricitywas estimated to be 48NGN.

4.0. CONCLUSION

The cost analysis for a wind turbine from E40 ENERCON Manufacturer with same specificationof the modelled wind turbine in this study was 114, 216,087 NGN. Therefore, the total cost of the proposed 5MW capacity power plant with ten wind turbines was 1, 142, 160, 870 NGN.

The net present value (NPV) was 1,689,076,215 NGN for free interest loan while 174,337,863.19 NGN was for 10% interest rate. The result indicated that the money earned on the investment is worth more than the cost. Therefore, the investment is good and profitable. The internal rate of return (IRR) of the investment when the capital is at 0% interest rate was 33.38% and for 10% interest rate was -84.74% respectively. Therefore, the investment is profitable at free interest rate. The payback period (PBP) is 10years which is an indication that the investment will breakeven at the tenth year. Levelized Cost of Electricity from the proposed wind farm gives the cost of producing electricity per kilowatt to be 47.9386 NGN kilowatt per hour which is cheaper than the conventional power. Therefore, the analysis of the study sitecan be used for establishment of wind farm.

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