A Socio-Engineering Economic Analysis of Wind Energy as an Alternative Electricity Generation Source in Nigeria

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***Abstract*-The study analysed the economic viability of wind energy alternative for generating 19 MW of electricity in Nigeria based on the Renewable Energy Master Plan (REMP) for the country. It also assessed the barriers to and drivers of wind energy utilisation in Nigeria. This was with a view to making appropriate strategic recommendations to guide policy makers in the implementation of wind power projects in the country. The study covered stakeholders in the electricity industry in both public and private sectors. Questionnaire and publications were used for data collection. The data collected were analysed using statistical and engineering economic methods. The results identified ten barriers to and seven drivers of wind energy utilisation in Nigeria. At the present tariff of Nigerian Naira (NGN), NGN12.12/kWh of electricity and diesel fuel cost of NGN160.00/litre, neither grid connected wind power nor off-grid wind/diesel hybrid power systems are economically viable. With the investment and operational costs remaining constant and varying the tariff upward, it was discovered that at a tariff of NGN18.00/kWh of electricity, the grid connected wind power system has a positive Annual Worth value. 937057.2 tons of GHG emissions could be avoided annually by installing 19 MW of wind energy as an alternative electricity generation source to diesel fuel in Nigeria.**

Keywords- Barriers; Drivers; Engineering-Economy Methods; Nigeria; Wind Power

I. INTRODUCTION

The nature and extent of energy demand and utilization in a national economy is, to a large extent, indicative of its level of economic development. To move toward a sustainable future, many reforms have been implemented, including those in the energy sector. In many sub-Sahara African (SSA) countries such as Cameroon, Nigeria, and the Democratic Republic of Congo, rolling blackouts have become common daily occurrences, resulting from the inadequacy of the electricity supply with an ever expanding demand, coupled with an aging electricity supply infrastructure, non-diversification of energy sources, and overloading of the existing electricity mains [1].

For a productive economy and for rapid, secured economic advancement, Nigeria, therefore must pay maximum attention to the optimal development and utilization of its energy resources and to the security of supply of its energy needs. Commercial electricity is generated mainly from hydropower and thermal power plants in Nigeria. Over the years, the availability of the power plants varied from about 27% to 40% of installed capacity due to technical problems and insufficient natural gas supply to fire the thermal plants [2]. There have been increasing efforts nationally and internationally to promote renewable energy as a response to the awareness of the limited supply of fossil fuels, to meet growing energy demand, and to reduce the harmful environmental impacts of fossil fuel use. To address these, there have been numerous studies to address the impact to local communities [3].

Consequently, the need to diversify into other energy alternatives for electricity generation was opted for through the utilization of the renewable energy resources. The integration of solar, hydropower, wind, biomass into the nation's electricity generation mix is aggressively being pursued [4]. Calculations using integrated assessment models, in which the economic and climate system are dynamically linked, show that if dangerous climate change is to be prevented, no more than 25% of global investment in generating plant should go to conventional fossil systems from the year 2010 upward. Indeed this share must drop below 20% by 2020, by which time more than 80% of investment would go to new, practically zero-emission power plants [5]. An option for this transformation of the generating mix toward low-carbon structure is the massive expansion of renewable [6].

One of the renewable energy sources, wind, is free from greenhouse gas (GHG) emission and is an inexhaustible energy source. It is available at annual average speeds of about 2.0 m/s at the coastal region and 4.0 m/s at the far northern region of the country. Assuming an air density of 1.1 kg/m3, wind energy intensity, perpendicular to the wind direction, ranges between 4.4 W/m^2 at the coastal areas and 35.2 W/m^2 at the far northern region [7]. In view of the energy available in the wind, Nigeria government came up with the following policies [4]:

- The nation shall commercially develop its wind energy resource and integrate this with other energy resources into a balanced energy mix.
- The nation shall take necessary measures to ensure that this form of energy is harnessed at sustainable cost.

One of the strategies to implement this policy was the development of the Renewable Energy Master Plan (REMP). This plan proposed generating 19 MW of electric power from wind energy by 2015 [7]. This study therefore is to analyse the economic viability of wind energy alternative for generating 19 MW of electricity in Nigeria by 2015 based on the REMP so as to guide policy planning and implementation.

II. MULTI-YEAR TARIFF ORDER

The Multi-Year Tariff Order (MYTO) provides a 15 year tariff path for the electricity industry in Nigeria. Under the 2012 Multi-Year Tariff Order (MYTO 2), retail tariffs place power consumers under five categories-Residential, Commercial, Industrial, Special Customers and Street Lighting [8]. Residential customers are further classified as- R1 (lowest-income consumers), R2- where most residential users of electricity belong (single and three phase), R3 (Low Voltage Maximum Demand) and R4 (High Voltage Maximum Demand). On the average, the document reveals that the R1 customers have the lowest bill, while energy charges for R2-R4 customers under the new tariff regime vary as shown in Table 1 below.

III. METHODOLOGY

This study employed both descriptive method of survey to enable the identification of barriers to and drivers of wind energy utilization, and engineering economy method to determine the breakeven tariff needed to provide a platform for sustainable power Generation, and how sensitive the wind power system is to several parameters whose outcomes are crucial to the success of the project. The study covers various stakeholders including selected four stakeholders in Nigeria electricity industry – Nigeria Electricity Regulatory Commission (NERC), Energy Commission of Nigeria (ECN), Rural Electrification Agency (REA), and Power Holding Company of Nigeria (PHCN); Nigeria Meteorological Agency (NIMET), Federal Ministry of Environment (FME) and two wind power consulting firms. Questionnaires were administered to the electricity stakeholders in the following proportions; NERC (16%), ECN (28%), PHCN (28%) and REA (28%). The questionnaires were used to collect primary data while secondary data were collected through journals, published and unpublished documents from the electricity stakeholders, NIMET, FME and wind power consulting firms. The data collected were edited, coded and analyzed using analysis of variance (ANOVA) and Duncan Multiple Range Test. Sensitivity and Breakeven analyses were used for the engineering economic analysis.

TABLE 1 AVERAGE TARIFF CHARGES (NGN/KWH) FOR THE YEAR 2012 – 2016 [PRODUCED FROM THE NIGERIAN ELECTRICITY REGULATORY COMMISSION (MYTO 2 MODEL-1)]

Tariff code	**Year**					**Year 2012 Estimated Customers**
	2012	2013	2014	2015	2016	
Residential						
R1	4.00	4.00	4.00	4.00	4.00	160505
R2	12.12	12.85	13.53	14.27	15.00	5443821
R3	34.00	34.36	35.27	36.25	37.41	5447
R4	31.41	32.01	33.52	35.19	37.04	262

IV. RESULTS AND DISCUSSION

A. *Socio-Economic Characteristics of the Respondents*

About 81% of the questionnaires administered were retrieved. The positions held by the respondents reveals that 14% were Directors and Senior Management Staff, 51% were Senior Scientific Officers and Engineers and 35% were Analysts and System/Plant Operators. 55.8% of the respondents were from electricity generation/transmission sub-sector, 25.6% were from the energy policy and environmental management sub-sectors while 18.6% were from regulatory sub-sector of the electricity industry. About 7.0% have PhD degree, 27.9% have M.Sc., 62.8% have first degree while 2.3% have other qualifications. About 58.1% of the respondents have at least one of the professional qualifications such as Council for the Regulation of Engineering in Nigeria (COREN), Nigeria Society of Engineers (NSE), Nigeria Institute of Management (NIM) and Institute of Electrical and Electronics Engineering (IEEE) while the remaining 41.9% have no professional qualifications. With the high educational qualification, position held and professionalism of the respondents, the information and data obtained from them are useful, relevant and adequate for the study.

B. *Barriers to and Drivers of Wind Energy Utilization in Nigeria*

Barriers to and drivers of wind energy utilisation in Nigeria were identified from published and unpublished journals [4, 7, 9, 10]. In the assessment, ANOVA was used to establish significant differences where there were ratings and Duncan Multiple

Range Test was used to separate the mean ratings. Table 2 shows the mean ratings of the identified barriers to wind energy utilization. There were significant differences (F = 11.80, P<0.05) among the ratings. High Initial Investment Cost (3.93), Liberalized Energy Industry (3.34) were rated most influential and significantly the same (F =11.80, P<0.05). Lack of Financial and Fiscal Incentives (2.95), Lack of National Renewable Portfolio Standard (2.88), Inadequate Institutional Framework (2.78) and Inadequate Resource Assessment (2.69) were rated next and significantly the same. As shown in Table 2, Intermittency of Resource Availability was not an influential barrier.

There were significant differences (F = 4.51, P<0.05) among the ratings on the level of implementation of the drivers to wind energy utilization as shown in Table 3. Development of the wind energy resource database (2.78), Promotional and advocacy activities on wind electricity (2.44) and R&D into wind electricity technology (2.12) were fairly implemented drivers but had the highest level of implementations and were significantly the same. Next on the rating were Incentive to local manufacturers/suppliers/users of wind electrical system components (1.70) and the Establishment of a regulatory framework for wind electricity (1.59), and were significantly the same. Investment subsidies (1.26) and Operation subsidies (1.24) had the least and were significantly the same.

The assessment clearly shows that the implementation of drivers of wind energy alternative for electricity generation in Nigeria is low, and there is a clear inverse correlation between the ratings of the drivers of and barriers to wind energy utilisation. The implementation of Investment and Operation Subsidies will mitigate the barrier posed by High Initial Investment Cost. Likewise, the Establishment of a Regulatory Framework for Wind (Energy) Electricity will reduce, if not eliminate, the barrier posed by a Liberalised Energy Industry. In summary, the cause and effect relationship of drivers and barriers were clearly justified in the ratings.

TABLE 2 BARRIER TO WIND ENERGY UTILIZATION IN NIGERIA

Factors	Rating Frequency				Mean Rating
	4	3	2	1	
High Initial Investment Cost	40(93.0)	3(7.0)			3.9275^{a}
Liberalized Energy Industry	19(44.2)	22(51.2)	1(2.3)	1(2.3)	3.3375^{ab}
Lack of Financial and Fiscal Incentives	6(14.0)	29(67.4)	7(16.3)	1(2.3)	2.9475^{b}
Lack of National Renewable Portfolio Standard (RPS)	8(18.6)	26(60.5)	7(16.3)	2(4.7)	2.8775^{bc}
Inadequate Institutional Framework	3(7.0)	28(65.1)	12(27.9)		2.7825^{bcd}
Inadequate Resource Assessment	5(11.6)	15(34.9)	23(53.5)		2.6900^{bcde}
Inadequate Policy Framework on Renewable Energy	3(7.0)	11(25.6)	19(44.2)	10(23.3)	2.2425^{cdef}
Noise Pollution	4(9.3)	3(7.0)	32(74.4)	4(9.3)	2.1625^{def}
Lack of Awareness	2(4.7)	7(16.3)	27(62.8)	7(16.3)	2.0875^{ef}
Intermittency of Resource Availability	7(16.3)	7(16.3)	14(32.6)	15(34.9)	1.9525^{f}

Source: Field Survey, 2012.
Key: Very Influential = 4, Influential = 3, Fairly Influential = 2, Not Influential = 1
Mean Ratings: Means with the same alphabetical letter (a-g) are not significantly different (F = 11.80, P<0.05).

TABLE 3 IMPLEMENTATION OF THE DRIVERS OF WIND ENERGY UTILIZATION IN NIGERIA

Factors	Rating frequency (%)				Mean Rating
	4	3	2	1	
Development of the wind energy resource database.	11(25.6)	22(51.2)	4(9.3)	6(14.0)	2.7700^{a}
Promotional and advocacy activities on wind electricity.	5(11.6)	20(46.5)	12(27.9)	6(14.0)	2.4400^{ab}
Research & Development into wind (energy) electricity technology.	2(4.7)	8(18.6)	32(74.4)	1(2.3)	2.1175^{abc}
Incentives to local manufacturers, suppliers and users of wind electrical system components.	1(2.3)	3(7.0)	21(48.8)	18(41.9)	1.7025^{bc}
Establishment of a regulatory framework for wind (energy) electricity.	2(4.7)	5(11.6)	15(34.9)	21(48.8)	1.5925^{bc}
Investment Subsidies	1(2.3)	3(7.0)	1(2.3)	38(88.4)	1.2550^{c}
Operation Subsidies	1(2.3)	3(7.0)		39(90.7)	1.2375^{c}

Source: Field Survey, 2012.
Key: Highly Implemented = 4, Implemented = 3, Fairly Implemented = 2, Not Implemented = 1
Mean Ratings: Means with the same alphabet letter (a-c) are not significantly different (F = 4.51, P<0.05).

C. Economic Breakeven and Sensitivity Analysis

Breakeven charts are very useful for analyzing new projects, for portraying and understanding the effects of variation in fixed and variable costs on the profitability of a business operation, and for other applications [11]. Thus, it was useful to analyze and portray the effect of the proposed MYTO on the net annual worth for determining the economic attractiveness of the proposed plant. By representing the revenue and costs of the wind power plant in the graphical form, it is possible to portray the net annual worth for any tariff level.

Line C'CF in Fig. 1 represents the fixed costs of generating electricity from wind power plant. Line C'CT shows the variation in total variable cost with output, and since its starting point is at C' (i.e., includes fixed costs), it actually represents total generation costs. The gross annual revenue is represented by line $0R_T$. The intercept of lines $0R_T$ and C'CT is called the breakeven point and the corresponding tariff, T_B, the breakeven tariff. At the breakeven tariff (T_B), under assumed linear relationships, annual total costs equal annual total revenue and the wind power producer will neither make a profit nor incur any loss.

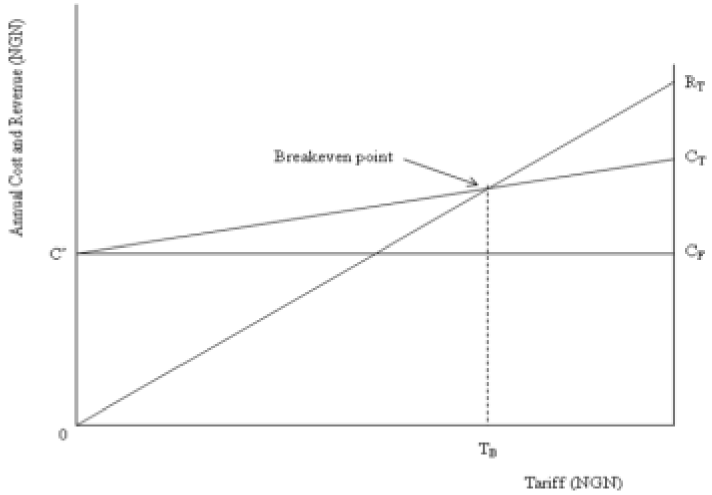

Fig. 1 Typical breakeven chart

The engineering economy study considers the time value of money and it was based on the assessment of the economic justification using Annual Worth (AW) method. A basic question this study addresses was whether the proposed wind power plant investment can be recovered by revenues (or savings) over time with the proposed MYTO. The AW of a project is its equivalent receipts (or savings) (R) minus annual equivalent expenses (E), less its annual equivalent capital recovery (CR) amount [11]. In equation form the AW is

$$AW = R - E - CR \tag{1}$$

As long as the AW is greater than or equal to zero, the project is economically attractive; otherwise, it is not.

D. Economic Analysis of Wind Power Systems

Grid connected wind power system and Off-grid wind/diesel hybrid power system were examined for the development of wind energy alternative. In analysing the economic viability, the capacity factor (CF) of 25% of the wind system was considered. The economic data used for the analysis were secondary data collected from NIMET, FME, wind consulting firms, publications, market survey and assumptions as shown in Table 4.

Examination of the annual worth of the project using the current tariff of NGN12.12/Kwh of electricity revealed that the project is not economically viable as the annual worth was negative as shown in Table 5. The values in this table assume that the plant would operate at 25% capacity factor (this value was based on the interview response from NIMET and FME and wind consulting firms, and may not be unconnected to average availability restriction due to intermittency caused by the monsoon/dry seasonal cycle) and the minimum attractive rate of return (MARR) of 18%. With cost remaining constant and varying the tariff rate upward, it was noted that the project is quite sensitive to price. At an increment of 48.5% of the present tariff (i.e. NGN18.0/kWh), the annual worth just become positive. Thus, the project would be economically attractive when tariff is increased to NGN18.0/kWh minimum from the current tariff of NGN12.12/kWh of electricity.

TABLE 4 ECONOMIC DATA FOR WIND AND DIESEL POWER PLANTS

Nos	Project specific and assumption factors			Source(s)
1	Initial Investment Cost (76MW Wind Plant)	15,000	NGN(million)	ECN; Wind Consulting Firms
2	Capacity Factor of Wind Turbine	25	%	Wind Consulting Firms; FME and NIMET
3	Equivalent Power Generation from 76MW Wind Plant	19.0	MW	Calculated

4	Useful life of Wind Turbine	25	Yrs	Wind Consulting Firms; FME; NIMET
5	Operation & Maintenance Cost of 76MW Wind Plant	1.5	NGN/Kwh	ECN
6	Salvage value 76MW Wind Plant (2% of Initial Investment Cost)	300	NGN(million)	Assumption
7	MARR	18	%	Wind Consulting Firms
8	Initial Investment Cost (20.2 MW Diesel Plant)	1494.8	NGN(million)	ECN
9	Diesel Generator availability	94	%	PHCN
10	Equivalent Power Generation from Diesel Plant	19	MW	Calculated
11	Useful Life of Diesel Plant	10	Yrs	PHCN
12	Operation & Maintenance Cost of Diesel Plant	3	NGN/Kwh	ECN
13	Salvage Value of Diesel Plant (2% of Initial Investment Cost)	29.9	NGN(million)	Assumption
14	Diesel Fuel Consumption	0.286	Litre/Kwh	PHCN
15	Cost of Diesel Fuel	105	NGN/Litre	Market Survey

TABLE 5 EFFECT OF VARIOUS TARIFF ON THE ANNUAL WORTH

Parameter	Tariff/Kwh			
	NGN4.40	NGN7.30	NGN12.12	NGN18.00 (48.5%)
Annual Revenue, (NGNm)	733.212	1215.888	2018.129	2993.467
Annual Cost, (NGNm)	2993.460	2993.460	2993.460	2993.460
Annual Worth, (NGNm)	-2260.248	-1777.572	-975.331	0.007

Sources and Methodology: Field Survey, 2012 and Engineering Economy method. Percentage values shown in parentheses are increments in price above NGN12.12

Installed Capacity is 76MW; Equivalent Power Generated is 19MW at 25% Capacity Factor

Fig. 2 shows the sensitivity analysis based on the economic tariff of NGN18.0/kWh of electricity and MARR of 18%. The graph is a linear graph with gradients for each of the parameter as 150 NGN(m)/% for initial investment, 150.138 NGN(m)/% for annual net cash flow, 0.048 NGN(m)/% for salvage value and 6.731 NGN(m)/% for useful life. Here it will be noted that the project is quite sensitive to initial investment and annual net cash flow. The analysis has revealed that an interplay between the barriers to and the drivers of wind energy utilization discussed earlier would facilitate the entry of wind power into Nigeria's electricity mix. For instance, if the initial investment which was rated the highest barrier to wind energy utilisation is reduced by introducing investment subsidy and incentives to manufacturers and suppliers of wind electrical equipment, which were unimplemented drivers, it would most likely influence the economic viability of a wind power plant positively. Also, government-sponsored loan insurance would likely mitigate initial investment barrier. Annual net cash flow can also be increased by increasing the electricity tariff, increasing the capacity utilization of the plant through research and development, reduction in the MARR and the introduction of operation subsidy through government policies. The project has a low sensitive to salvage value and useful life.

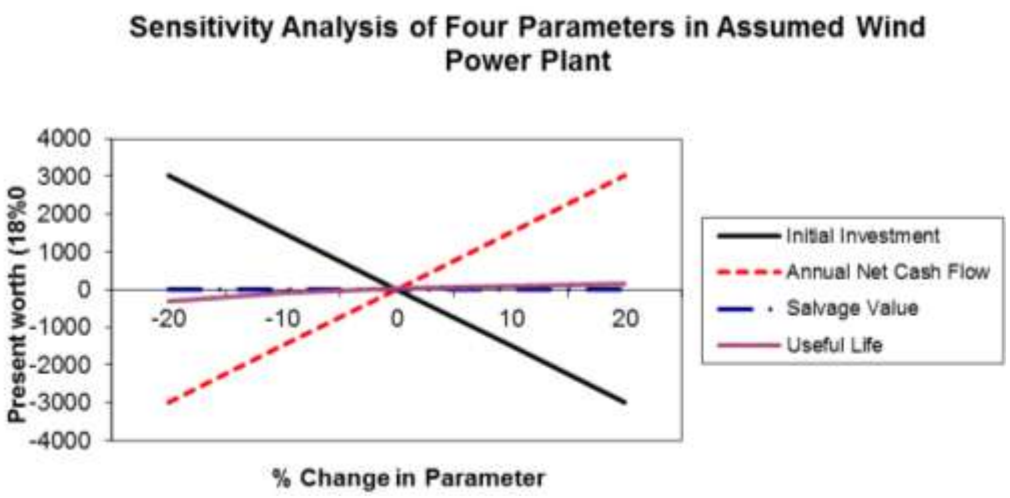

Fig. 2 Sensitivity analysis of four parameters in proposed wind power plant

For the wind/diesel hybrid power system, the economic analysis was carried out based on the annual worth of a stand alone diesel power plant and a stand alone wind power plant which will help in determining the penetration of the wind turbine in the hybrid system.

The economic feasibility analysis of a stand alone diesel generator plant is shown in Table 6. Assuming the tariff of NGN18.00/kWh of electricity that is economically viable for the wind power plant (Table 5), it was observed that annual worth of a stand alone diesel generator of the same equivalent power generation with the wind turbine (19 MW) was less than zero (NGN-4.2 b) when the cost of diesel is NGN160/litre. For the diesel generator to be economically viable at the economic attractive tariff of NGN18.0/kWh, the cost of diesel/litre has to be reduced by about 71.6% (i.e NGN45.4) as illustrated in Table 6.

It can be seen from Table 5 and Table 6 that when the cost of diesel is NGN160/litre and tariff of electricity is NGN18.0/kWh, it is economically attractive to generate electricity from wind (AW= NGN0.007m) but not from diesel power plant (AW=NGN-4.2b). Without subsidy, wind power plant is more economically attractive than a diesel power plant. Thus for the wind/diesel hybrid system, wind turbine should have the maximum possible penetration in order to obtain maximum Annual Worth.

TABLE 6 ECONOMIC FEASIBILITY ANALYSIS RESULT FOR STAND-ALONE DIESEL GENERATOR PLANT

Parameter	Cost of Diesel Fuel NGN/litre			
	160	105 (34.4%)	45.40 (71.6%)	26.25
Annual Revenue (NGNm)	2997.191	2997.191	2997.191	2997.191
Annual Cost (NGNm)	7192.2149	5830.1211	2993.0514	2081.4762
Annual Worth (NGNm)	-4195.0239	-2832.9301	4.1396	915.7148

Source and Methodology: Field Survey, 2012 and Engineering Economy method.
Percentage values shown in parentheses are reduction in price below NGN160

E. Green House Gas (GHG) Emissions Analysis for the Wind/Diesel Hybrid System

Assuming a 5% maximum penetration limit from a wind farm to a mini-grid, the minimum grid capacity for connecting a 19MW wind turbine with diesel generator will be 380MW. If 19MW of electricity is supplied by the wind turbine into a wind/diesel hybrid power system, the annual energy generated from the wind turbine will be 166,440,000 KWh, and annual diesel savings for utilizing wind energy as an alternative to diesel fuel will be 47,601,840 litre. Besides, it is well known that the rate of CO_2, SO_X and NO_X emission/KWh from a diesel generator can vary widely depending on generator type, size and load factor. Thus, if a 380MW stand-alone diesel generator is replaced with a 380MW wind/diesel hybrid power system in which the wind turbine can generate 19MW maximum electricity, then the annual reduction of CO_2, SO_X and NO_X will be 129,823.2, 8,322 and 798,912 ton respectively, making a total of 937057.2 tons. This was estimated from the annual wind turbine generation of 166,440,000KWh and CO_2, SO_X and NO_X emission amount of 0.78Kg/KWh, 0.05Kg/KWh and 0.0048Kg/KWh respectively.

V. CONCLUSION

Wind energy utilization for electricity generation will add more energy to the nation’s electricity grid, thereby reducing blackouts and brownouts, rolling, scheduling of electricity supply. It will also minimize the time, energy, and productivity lost in start-ups and shutdowns of industrial, residential, and commercial processes as a result of inadequate electricity supply. These losses, though significant, are widely dispersed among the population, but have not been quantified in this study, minimizing them will therefore increase the contribution of energy to the nation’s Gross Domestic Product (GDP). Wind energy is considered a viable solution to the electricity challenges of Nigeria especially in the rural areas of the country and to the restrictions posed by the gas supply limitation to the national grid thermal plants. Generating electricity from wind energy as an alternative energy source will also reduce GHG emission drastically, thus reducing the harmful environmental impacts of fossil fuel use and improving energy diversification.

In order, for Nigeria to be able to utilize its wind energy resources for electricity generation; economic, policy and market drivers should be adequately implemented to reduce the influence of barriers to wind energy utilization. To meet these goals, the following recommendations have been suggested.

- An attractive tariff of electricity should be introduced, say at least NGN18.00/kWh
- Some economic incentives such as investment subsidy, operation subsidy and government-sponsored loan insurance (with a lower or no interest rate) that will reduce annual cost and attract investors should be adequately implemented.
- Appropriate implementation of a regulatory framework for wind energy will reduce, if not eliminate, the barrier posed by a Liberalised Energy Industry.

- Increased research and development in wind energy resource database, wind speed forecasting and wind technology should be pursued as increase in the capacity utilization of the plant increases annual net cash flow.

- All of these together or a mixture of any of these may be considered depending on the socio-political implications of their implementation.

It should be noted that as carbon trading continues to be implemented on both national and international scale, it is becoming an important factor in renewable energy investment decisions [12]. Hence, Nigeria being a signatory to the Kyoto Protocol stands to benefit from the Clean Development Mechanism (CDM) of the Kyoto Protocol on wind energy investment decisions if she vigorously pursues the development of her wind energy resources.

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