Techno-Economic Analysis of NERC's Feed-in-Tariff for Sustained Grid-Connected Renewable Power Supply: Case of 3 Selected Sites of Northern Nigeria

Adekojo Waheed, Oluseyi. O Ajayi, O. David Ohijeagbon

***Abstract*— The study aimed at determining the techno-economic viability of renewable energy mix for sustained power supply in 3 sites of Northern Nigeria. It investigated the viability of grid connected renewable power sources of PV standalone, Wind standalone and PV-Wind Hybrid systems. Three sites were selected to ascertain the feasibility of producing energy from renewable sources, while considering the prevailing regulations and feed-in tariff for renewable electricity in Nigeria as stipulated by the Nigerian Electricity Regulatory Commission (NERC). NERC used the Weighted Average Cost of Capital (WACC) to determine the Feed-in-Tariff for power generation. The 24 years daily global solar radiations, maximum and minimum daily temperature data and wind speed data that were employed for this study were provided by the Nigeria Meteorological agency (NIMET), Oshodi, Lagos, Nigeria. Optimised designs were developed for each location. The results showed that with the current real WACC stipulated in NERCs Regulations on Feed-in Tariff for Renewable Energy Sourced Electricity in Nigeria, the Wind standalone system was found to be most suitable for Katsina (North-west) and Ilorin (North-central), while the PV-Wind hybrid system only slightly improved the viability of harnessing the RE resources of solar PV and wind energy at a debt to equity ratio of 70 to 30%. However, if the WACC is improved such that the real WACC is reduced by 5%, all the three PV standalone power plants become viable, alongside all of the Wind standalone power plants in terms of Net Present Value and annual profits. Hence, this study reveals that with proper economic incentives, RE for grid generation can be profitable in Nigeria.**

***Index Terms*— Wind power, wind turbine, solar power, hybrid energy system, energy systems, electric power systems, renewable energy**

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I. Introduction

Electricity is fundamental to development. It is a means to improved social and economic well-being just as it is vital to industrialization and wealth creation. It is also the gateway to employment opportunities. The nation's pursuit of becoming one of the 20 most developed countries in the world by 2020 requires adequate supply and access to modern power. The energy policy document of the federal government's vision 20:2020 stipulates the desire of the government to use energy as one of the tools to drive the developmental stride of making Nigeria become one of the top 20 economies in the world by the year 2020 [1-2]. This therefore makes access to modern energy pivotal to the development agenda of Nigeria. However, present situation suggests more efforts are required to resolve the imbalance between demand and supply of electricity in the country. A moderate estimation of power generated by households and industrial sectors from petrol and diesel generators falls at about 2500 MW [3]. This unsustainable means of power generation is both environmentally unfriendly and costly. It usually brings about upsurge in the cost of doing business and also costly products. The consequence may be attributed to underperforming manufacturing sector. Recent statistics in 2013 showed that the manufacturing sector contributed 4% toward the Gross Domestic Product (GDP). This is poor and need improvement when compared to other national figures such as 35% in Thailand, 34% in China, 30% in Malaysia, 28% in Indonesia, and 19% in India [4-13]. Aside this, the small and medium scale enterprise will be the most underdeveloped sector in a situation of lack of access to modern power supply. This sector has been known to provide several employment opportunities [3], and can contribute to national well-being of the populace. One major way out of the energy situation of Nigeria, according the policy document of vision 20:2020 is for Nigeria to have a robust energy mix which will include the conventional generation as well as renewable energy generation as standalone and grid connected facilities.

II. Review of Previous Studies

Based on the aforementioned, several assessment studies have been carried out at both national level and by individual researchers at determining the viability of renewable energy adoption for power generation [14-21]. For instance, in Nigeria many research studies exist that have appraised the potential of hybrid Renewable Energy (RE) system for power generation [22-25]. However, most of the existing study reports considered small scale generation for remote telecom applications and for buildings. Others that focused on grid connected systems only served to verify the possibility of scaling up the designed renewable energy generation sources to the MW range, to benefit from the allowance provided through embedded generation [26]. Moreover, studies on design and econometrics analysis of hybrid systems that provide sustainable power as grid-alone systems in the form of power plants are rare. Also, the impact of the national feed-in-tariff system as developed by the Nigerian Electricity Regulatory Commission (NERC) has never been analysed to determine its economic viability and investor friendliness. This study is therefore focused on the techno-economic assessment of hybrid RE for sustainable power supply in Northern Nigeria. The selection of this region for an evaluation of the feasibility of sustained power supply via RE is predicated on the fact that a lot of studies have proven that Northern Nigeria is endowed with vast RE resources [27-29]. Also, at present the large sized power plants installed in Northern Nigeria are predominantly the Hydroelectric Power Plants. Three sites, one each, of the three geo-political zones in this region of the country were considered in this study.

III. PRESENT WORK

This present work aims at determining the techno-economic viability of the national feed-in-tariff system for grid connected PV standalone, Wind Standalone and PV-Wind Hybrid systems in selected sites from the three geo-political zones of Northern Nigeria. Three sites were selected to ascertain the feasibility of producing energy from renewable sources, while considering the prevailing regulations and feed-in tariff for renewable electricity in Nigeria as stipulated by NERC [30]. The result of this research will aid the decision-making process by potential investors, as regions and locations where a specific renewable standalone system is viable are highlighted.

IV. MATERIALS AND METHODS

The geographical description of the location of the selected sites are as displayed in Table 1.

A. Data Collection

The 24 years' daily global solar radiations, maximum and minimum daily temperature data and wind speed data that were employed for this study were provided by the Nigeria Meteorological agency (NIMET), Oshodi, Lagos, Nigeria

Tables 2 to 5 present the basis of calculating NERC's feed-in tariff in \$/MWh for Renewable Electricity in Nigeria [30]. NERC utilized the Weighted Average Cost of Capital (WACC) in arriving at the Feed-in Tariff for power generation. WACC is a calculation of a business entity's cost of capital in which each classification of capital is proportionally rated. All sources of capital, which include common stock, preferred stock, bonds, and other long-term debt can be included in WACC calculation. The ratio of equity to debt was used in weighting the equity and debt returns in the WACC calculation.

The WACC was estimated by NERC with the following assumptions [30]:

Risk free rate	18%
Nominal cost of debt	24%
Nominal return on equity	29%
Gearing level (debt/equity)	70% / 30%
Corporate tax rate	32%

The assumptions provide the basis for the following estimates:

Nominal before tax WACC	25%
Nominal after tax WACC	17%
Real pre-tax WACC	11%
Real after tax WACC	7%

The minimum permissible amount of power generated that can be fed into the national grid at any given instance is 1 MW. Therefore, the renewable energy systems designed in this study worked with capacities of Solar PV array sizes and Wind Turbine models that will optimally take advantage of the Feed-in tariff as captured in Table 5. Table 6 displays the cost for each constituent of the hybrid system [31].

B. Modelling the Photovoltaic (PV) and Wind Power System

Design equations and formulas utilized for both PV and wind analyses were those of: Duffie and Beckman, [32], and Erbs et al. [33] used in the design of solar PV systems, and Weibull probability density function [34], Hiester and Pennell [35], and Le Gouriérès [36] used in the design for wind energy systems.

To accurately determine the feasibility and sustainability of these systems, the HOMER® software optimizing tool [37] was used in carrying out the sensitivity analysis and optimisation.

C. Modelling the Photovoltaic (PV) and Wind Power System

For each component according to Ohijeagbon and Ajayi [26], the salvage value, maintenance, capital and fuel costs, together with other sundry costs or revenues for all the components sum up to the system's annualized cost. The total net present cost (NPC) and other cost components were determined based on equations and derivations profiled in Ohijeagbon and Ajayi [26].

TABLE 1
LOCATION PARAMETER OF THE STUDIED SITES

S/N	Geopolitical Zone	State	Sites	Latitude (° N)	Longitude (° E)
1	North West (NW)	Katsina	Katsina	12.9833	7.6000
2	North East (NE)	Taraba	Ibi	8.1850	9.7450
3	North Central (NC)	Kwara	Ilorin	8.5000	4.5500

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TABLE 2
BENCHMARK CAPACITIES FOR QUALIFYING TECHNOLOGY

Technology	Minimum Capacity (MW)	Maximum Capacity (MW)
Wind	1	10
Small Hydro	1	30
Biomass (including municipal solid waste)	1	10
Solar Photovoltaic	1	5

TABLE 3
TARGET GRID-CONNECTED RENEWABLE GENERATION CAPACITY BY THE YEAR 2018

Technology	Capacity Limit (MW)
Wind	100
SHP	370
Biomass	150
Solar Photovoltaic	380

TABLE 4
ASSUMPTIONS FOR RENEWABLE ENERGY FEED-IN TARIFF COMPUTATION

Description	Unit	Solar	Small Hydro	Biomass	Wind
Capacity	MW	5	30	10	1760
Capacity Cost	$/kW	1500	3100	2900	32%
Capacity Utilization factor	%	19%	45%	60%	18.5
Fixed O & M	$/kW/yr	30	23	53.5	1.48
Variable O & M	$/MWh	0.06	0.25	0.95	1.48
Fuel Cost	$/MWh	0	0	4	0
Aux. Power requirement	%	1	1	10	1
Decline rate of price	%	5	5	5	5
Construction time	Year	2	3	2	2
Exchange rate (₦ to $)	Naira	200	200	200	200
Real WACC	%	11	11	11	11
Local Inflation	%	8.3	8.3	8.3	8.3

TABLE 5
FEED-IN TARIFF FOR 2016 BASE YEAR

Year	Description	Units	Solar	Wind
FIT2016 (Naira)	Capacity Cost	₦/MWh	35,370.05	24,791.55
	O & M	₦/MWh	29.49	302.73
	Total	₦/MWh	35,399.54	25,094.28
FIT2016 (US$)	Capacity Cost	$/MWh	176.85	123.96
	O & M	$/MWh	0.15	1.51
	Total	$/MWh	177.00	125.47

TABLE 6
COST OF COMPONENTS USED IN THE DESIGN OF HYBRID ENERGY SYSTEM [31]

Component	Annual Real Interest Rate (%)	Project Life time (years)	Cost ($/kW)	O & M ($)	Replacement Cost ($/kW)
Wind turbine	11 & 6	15	1800	500/yr.	1500
Solar panel	11 & 6	25	1500	0/yr.	1000
Battery	11 & 6	10	100	20/yr.	100
Converter	11 & 6	12	500	80/yr.	500

E. Solar and wind turbine systems specification

The Enercon wind turbines were cumulatively employed for wind standalone and wind-PV hybrid applications. The turbine specification is indicated in Table 7. A 1 kW SUNPOWER mono-crystalline silicon cell was used [26, 32, 38]. The cell parameters are:

Collection area	5.1 m^2
Efficiency, η	19.6%
Nominal operating temperature	45 ^oC
Temperature coefficient	0.4%
Miscellaneous losses	10%
Array slope	site's latitude angle

V. RESULTS AND DISCUSSION

Viability of standalone PV in the selected sites

Fig. 1 presents the monthly average solar radiation profiles of the selected sites. The figure shows that the 24 years' monthly average ranged between 3.913 (kWh/m²/d) in August for Ilorin and 6.356 (kWh/m²/d) in April for Katsina.

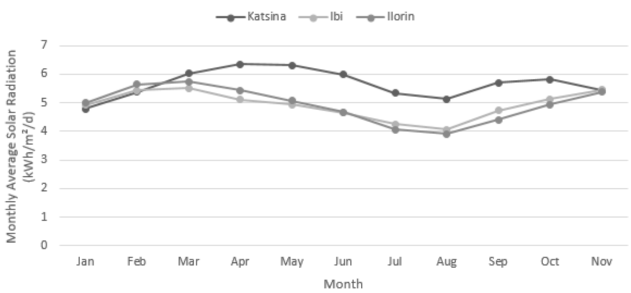

Fig 1: 24- Year Monthly Average Radiation (kWh/m²-day) for selected sites in Northern Nigeria

From Table 8, it can be inferred that PV standalone power plants installed across the sites did not breakeven at two of the proposed locations. Katsina breaks-even with a Net Present Value (NPV) of US$ 335,685.00 and an LVOE of $0.003/kWh. Based on the results, the PV standalone power systems (PSS) did not break-even all through the project life span of 25 years when the NERC's feed-in-Tariff regime of 11% was used. On the other hand, when the debt to equity ratio was improved or special funding was assumed realized through government grants, carbon financing, etc., such that the real WACC was remodelled to 6%, remarkable changes were observed for all the studied locations. Ilorin and Ibi became viable for PSS, together with an increase in revenue generation at Katsina. Tables 8 & 9 both reflect a ranking of the degree of viability of PSS amongst the selected locations. For Table 9, it is worthy of note that a negative

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LCOE and NPC refers to the Value of Energy per kW and the Net Present Value of the project respectively. Upon comparison of Table 8 and 9, it is apparent that the optimal techno-economic design for each location increased. Hence, more energy was produced and more grid sales were made. The total annualized costs represent the actual annual profit or loss incurred yearly. A negative annual cost implies the value of annual profits made at the respective location.

TABLE 7
WIND TURBINE SPECIFICATION

Wind Machine	V_c (m/s)	V_{Fi} (m/s)	V_{Fo} (m/s)	V_R (m/s)	P_{eR} (kW)	Hub Height (m)	Rotor Diameter (m)
Enercon	3	2	25	12	3000	135	101

V_c = cut-in speed, V_{Fi} = cut-out speed (low wind), V_{Fo} = cut-out speed (high wind), V_R = rated speed, P_{eR} = rated power

Viability of wind turbine standalone system (WSS)

Fig. 2 shows the average monthly wind speed profiles of the sites. It depicts that the 24 years' wind speed ranged between 2.95 m/s in June for Ibi and 9.89 m/s in June for Katsina.

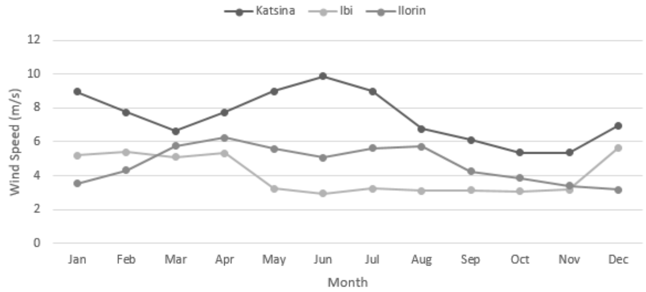

Fig. 2: Plot of 24 Years' Monthly Average Wind Speeds for selected locations in Northern Nigeria

From Table 10, WSS is not economically feasible at Ibi, while Katsina is the most viable, with a Net Present Value of US$28,215,764.00 and an LVOE of $0.072/kWh. Also, based on the NERC's feed-in-Tariff regime of 11%, 2 of the three sites are economically viable for wind power generation. Moreover, Ibi's result shows that with slightly improved wind speed profile, WSS will be a viable power resource.

However, if the debt to equity ratio is improved or special funding was realized, such that the real interest rate is remodelled to 6%, remarkable changes are observed for all 3 sites in terms of energy production and profits. Tables 10 & 11 both reflect a ranking of the degree of viability of Wind standalone systems amongst the selected locations.

TABLE 8
OPTIMIZED ASSESSMENT OF THE PV STANDALONE POWER PLANT IN TERMS OF 11% REAL INTEREST RATE.

Location	PV Size (kW)	Converter (kW)	Initial Capital ($)	Total Annual Cost ($/yr)	Mean Power Output (kW)	Total NPC ($)	LCOE ($/kWh)	PV Production (kWh/yr)
Katsina	8000	5000	14,502,000.00	-39,859.00	1,593	- 335,685.00	-0.003	13,995,402
Ilorin	5750	3500	10,377,000.00	137,169.00	1,020	1,155,202.00	0.018	8,936,367
Ibi	6000	3500	10,752,000.00	146,337.00	1,060	1,232,409.00	0.019	9,289,647

TABLE 9
OPTIMIZED ASSESSMENT OF THE PV STANDALONE POWER PLANT IN TERMS OF 6% REAL INTEREST RATE

Location	PV Size (kW)	Converter (kW)	Initial Capital ($)	Total Annual Cost ($/yr)	Mean Power Output (kW)	Total NPC ($)	LCOE ($/kWh)	PV Production (kWh/yr)
Katsina	10000	5000	17,502,000,00	-676,933.00	1,991	-8,653,476.00	-0.049	17,444,232
Ibi	10500	5000	18,252,000.00	-445,138.00	1,856	-5,690,361.00	-0.035	16,256,893
Ilorin	10500	5000	18,252,000.00	-450,117.00	1,863	-5,754,006.00	-0.035	16,318,597

TABLE 10
OPTIMIZED ASSESSMENT OF THE WIND STANDALONE POWER PLANT IN TERMS OF 11% REAL INTEREST RATE

Location	Wind Turbine (kW)	Initial Capital ($)	Total Annual Cost ($/yr)	Mean Power Output (kW)	Total NPC ($)	LCOE ($/kWh)	Wind Production (kWh/yr)
Katsina	12000	21,020,500.00	-3,923,832.00	7,078	-28,215,764.00	-0.072	62,001,108
Ilorin	12000	21,020,500.00	-848,607.00	3,675	-6,102,224.00	-0.028	32,189,926
Ibi	9000	15,770,500.00	38,936.00	1,961	279,982.00	0.002	17,181,262

TABLE 11
OPTIMIZED ASSESSMENT OF THE WIND STANDALONE POWER PLANT IN TERMS OF 6% REAL INTEREST RATE

Location	Wind Turbine Size (kW)	Initial Capital ($)	Total Annual Cost ($/yr)	Mean Power Output (kW)	Total NPC ($)	LCOE ($/kWh)	Wind Production (kWh/yr)
Katsina	12000	21,020,500.00	-4,682,724.00	7,078	-45,479,776.00	-0.086	62,001,108
Ilorin	12000	21,020,500.00	-1,607,500.00	3,675	-15,612,436.00	-0.053	32,189,926
Ibi	12000	21,020,500.00	-563,663.00	2,615	-5,474,433.00	-0.026	22,908,292

Evaluation of the potential of Solar-Wind Hybrid system

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Table 12 presents the feasibility assessment for the optimal PV-Wind hybrid design for the three selected sites. It was discovered that the hybrid system improved the NPC of Ibi over the PSS and WSS projects at 11% real WACC. The LCOE value for Ibi, for PSS and WSS was $0.019/kWh and $0.002/kWh respectively. However, with the Wind-PV hybrid set-up, the LCOE becomes $0.001/kWh. For Katsina, in North West Nigeria, and Ilorin, in North Central Nigeria, the same WSS design setup was the optimized value for the hybrid system, as zero kilowatt for wind and PV were included in the sensitivity analysis during optimization. Hence, the Wind-PV hybrid is proven to be less viable than an equivalent WSS at these locations.

Table 13 reveals that at a 6% real interest rate, hybrid installation at Ibi becomes viable over the respective PSS and WSS installed at this same location.

Tables 14 – 16 highlight the significance of an improved government intervention on the promotion of RE for grid-generation. The Results indicate that investment at NERC's regulation of 11% Real Interest Rate (RIT) will bring about:

- Losses in solar PV investment of between $137,169 and $146,337 per year in two of the three sites.
- Losses in wind power investment of just $38,926 per year at Ibi alone.
- Losses in hybrid systems investment of about $14,729 for Ibi, which is an improvement on the losses incurred on both the PSS and WSS at the same location.

A remodeling to 6% RIT brings about profits at all sites for both the PSS and WSS:

- Profit of between $450,117 and $676,933 from solar PV per year.
- Profit of between $563,663 and $4,682,724 from wind power per year.

Table 16 demonstrates that hybrid system for grid generation of RE is the only preferred for better returns on investment at Ibi (North-East) with NERC's regulation of 11% Real Interest Rate. For all other regions, the WSS fared better than their respective PSS and hybrid configurations. Moreover, the results demonstrate that with proper feed-in-Tariff regime systems, the power generation from renewable energy resources, especially from wind and solar can be very profitable and attractive to investors. Hence, suggesting that the Federal government of Nigeria need to reconsider the tariff regime in a bid to remodel it for the economic benefit of investors and thereby promote the adoption of renewable power systems.

TABLE 14
PV STANDALONE POWER PLANT IN TERMS OF 11% AND 6% REAL INTEREST RATES (RIT)

Location	PV Sales (kWh/yr.) at 11% RIT	Profit ($/yr.) at 11% RIT	PV Sales (kWh/yr.) at 6% RIT	Profit ($/yr.) at 6% RIT
Katsina	12,039,241	39,859.00	13,727,783	676,933.00
Ilorin	7,697,124	(137,169.00)	12,749,677	445,138.00
Ibi	7,896,896	(146,337.00)	12,777,895	450,117.00

TABLE 15
WIND STANDALONE POWER PLANT IN TERMS OF 11% AND 6% REAL INTEREST RATES (RIT)

Location	Wind Production (kWh/yr.) at 11% RIT	Profit ($/yr.) at 11% RIT	Wind Production (kWh/yr.) at 6% RIT	Profit ($/yr.) at 6% RIT
Katsina	54,587,468	3,923,832	54,587,468	4,682,724
Ilorin	30,077,842	848,607	21,758,430	1,607,500
Ibi	17,181,250	(38,936)	30,077,842	563,66

TABLE 16
WIND-PV HYBRID IN TERMS OF 11% AND 6% REAL INTEREST RATES (RIT)

Location	Wind-PV Production (kWh/yr.) at 11% RIT	Loss ($/yr.) at 11% RIT	Wind-PV Production (kWh/yr.) at 6% RIT	Profit ($/yr.) at 6% RIT
Ibi	18,526,718	(14,749)	20,393,856	780,547.00

VI. CONCLUSION

The study investigated the economic viability of the NERC's feed-in-tariff system for grid connected renewable power of PV standalone, Wind Standalone and PV-Wind Hybrid systems. It employed data for three selected sites from northern Nigeria to ascertain the plausibility of producing energy from renewable resources, while

TABLE 12
OPTIMIZED ASSESSMENT OF THE WIND-PV HYBRID STANDALONE POWER PLANT IN TERMS OF 11% REAL INTEREST RATE

Location	Wind Turbine Size (kW)	PV Size (kW)	Converter (kW)	Initial Capital ($)	Total Annual Cost ($/yr)	Mean Power Output (kW)	Total NPC ($)	LCOE ($/kWh)	Energy Production (kWh/yr)
Katsina	12000	0	0	21,020,500.00	-3,923,832.00	7,078	-28,215,764.00	-0.072	62,001,108
Ilorin	12000	0	0	21,020,500.00	-848,607.00	3,675	-6,102,224.00	-0.028	32,189,926
Ibi	6000	5500	3000	20,302,000.00	14,749.00	2,274	124,212.00	0.001	19,969,656

TABLE 13
OPTIMIZED ASSESSMENT OF THE WIND-PV HYBRID STANDALONE POWER PLANT IN TERMS OF 6% REAL INTEREST RATE

Location	Wind Turbine Size (kW)	PV Size (kW)	Converter (kW)	Initial Capital ($)	Total Annual Cost ($/yr)	Mean Power Output (kW)	Total NPC ($)	LCOE ($/kWh)	Energy Production (kWh/yr)
Katsina	12000	0	0	21,020,500.00	-4,682,724.00	7,078	-45,479,776.00	-0.086	62,001,108
Ilorin	12000	0	0	21,020,500.00	-1,607,500.00	3,675	-15,612,436.00	-0.053	32,189,926
Ibi	6000	7000	3750	22,927,000.00	-780,547.00	2,545	-9,978,004.00	-0.038	22,292,063

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considering the prevailing regulations and feed-in tariff for renewable energy sourced electricity in Nigeria as stipulated by the NERC. Optimised designs were developed for each location. The results showed that with the current NERCs

Regulations on Feed-in Tariff for Renewable Energy Sourced Electricity of 11% Real Interest Rate, the drive towards attraction of investors will be greatly hindered. However, if the WACC is improved such that the real WACC is remodelled to 6%, renewable electricity will be economically viable across the three sites. Hence, the impact of the NERC's economic model on returns on investment as it relates to wind and solar power technologies for grid generation was demonstrated. The outcome further showed that with proper economic incentives, RE for grid generation can be profitable in Nigeria.

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