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Economic Evaluation of Hybrid Renewable Energy Systems for Electricity Generation in Nigeria: A Discounted Cash Flow Analysis

Michael Aba[1], Ayodeji Ladeinde[1] and Emmanuel Afimia[1*]

[1]Afimia Consulting Services, Nigeria.

Authors' contributions

All the authors contributed equally to this study. All authors read and approved the final manuscript.

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ABSTRACT

Nigeria has great renewable energy resource potential comprising solar, wind, biomass and hydro and much work has been done on estimation of this potential. Variability of a single resource type, high cost of energy from renewable sources and impracticability of grid extension to distant rural areas from the national grid has led to the development of hybrid renewable energy systems (HRES). Although Nigeria is rich in these renewable resources, a hybrid application approach seems more feasible to ensure a reliable and cost-effective power supply from these sources. This study was conducted to assess Nigeria's technological readiness for adopting HRES, its environmental impact and its viability over a 20-year period. A review of past literature was carried out to ascertain the country's readiness for HRES and its environmental impact, while the discounted cash flow (DCF) analysis, along with other economic indicators of net present value (NPV), internal rate of return (IRR) and payout period (PO) were adopted to estimate the economic viability of the system. The outcome of this paper shows that HRES for power generation in Nigeria is economically viable.

**Corresponding author: E-mail: afimiaconsultingservices@hotmail.com, afimiaemmanuel@gmail.com;*

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1. INTRODUCTION

Nigeria is a country rich with great renewable energy resource potential comprising solar, wind, biomass and hydro and much work has been done on estimation of this potential. Variability of a single resource type, high cost of energy from renewable sources and impracticability of grid extension to distant rural areas from the national grid has led to the development of hybrid renewable energy systems (HRES) [1]. Although Nigeria is rich in these renewable resources, a hybrid application approach seems more feasible than a single renewable energy approach to ensure a reliable, sustainable and cost-effective power supply from these sources. In the light of the foregoing, the objective of this paper is to conduct an economic evaluation of hybrid renewable energy system for electricity generation in Nigeria.

Section 2 discusses the review of related literature. The methodology employed to conduct the economic evaluation of the system is expressed in section 3, while section 4 discusses the result of the analysis. Finally, the conclusion and recommendations of this study are contained in Section 5.

2. LITERATURE REVIEW

2.1 Hybrid Renewable Energy System (HRES)

The outcome of the assessment conducted by Evans et al. [2] on the available renewable technologies was considered in selecting the combination of RETs to be included in the HRES. Thus, solar photovoltaic (PV) and wind technologies have been selected for inclusion in the HRES. These two types of RETs were selected because, as posited by Evans et al. [2], wind is the most sustainable RET, while PV is the third most sustainable RET in the world.

Nigeria has a daily average solar radiation of about 12.6MJ/m^2/day (equivalent of 3.5 kWh/m^2/day) in the coastal region and 25.2 MJ/m^2/day (equivalent of 7.0 kWh/m^2/day) in the northern part of the country; and an annual wind speed at 10m above the ground which varies from 2.3 – 3.4m/s along the coastal regions and 3.0 – 3.9m/s from high land areas and semi-arid regions of the country [3]. These make the climatic condition of the environment suitable for the adoption of solar PV and wind technology. The two RETs are expected to play complementary roles; while solar will supply power during sunny days and periods of low wind speed, wind will supply power at night and during rainy season when solar will not be able to power the solar cells [2,4]. In addition to PV panels and turbines, inverters and batteries are needed within the system.

The battery chargers receive energy directly from the PV and wind turbines which passes through the system to consumers. Batteries store excess energy from the renewable sources which is used up in periods of low solar radiation and low wind speed. The inverter, however, convert's direct current (DC) to alternating current (AC). This can be seen in Fig. 1 [5].

2.2 Technological Readiness of Nigeria for HRES

RETs have been adopted by many countries of the world, and many researchers have expressed Nigeria's readiness to adopt these technologies. Renewable energy is feasible in solving Nigeria's energy problems in the rural and urban centers because of the country's huge renewable energy potential [6]. The country stands to benefit a lot by promoting the use and inclusion of renewable energy technologies in its energy mix [7]. In the light of this, many renewable energy projects have been built across the country, but are mostly single system renewable energy projects [8]. The spread of these projects across Nigeria can be seen in Table 1.

As shown in Table 1, as at 2014, the number of renewable energy projects in Nigeria stood at thirteen (13) with solar energy system having the highest number followed by small hydro power and then wind. This goes to show the country's readiness for renewable energy technologies. Almost all the states in Nigeria have huge potentials for 2 or more renewable energy sources, however, the country needs to harness these sources of energy by encouraging investments in renewable energy technologies [3].

As posited by Adaramola et al. [9], wind energy will be more efficient in the Delta region in a hybrid energy system of wind-PV-diesel generator than if it operates as a single system. This is attributable to the wind speed in that region. Solar PV and wind energy sources when combined as a hybrid system are capable of supplying electricity to a building thereby reducing the load on the national grid [10]. Incorporating power conversion and storage units into a hybrid wind-solar energy system is a good combination for supplying electricity to the national grid [11].

Smart grid technologies and renewables should be integrated into Nigeria's energy mix in order to augment the supply of electricity from natural gas and hydro sources to the national grid [12]. Renewable energy is possible and the regulatory framework that seeks to ensure the integration of these technologies into the country's energy mix has been developed by NERC.

To fully ensure welfare maximization of the citizens through the provision of constant power supply, Nigeria's electricity sector needs the urgent attention of the government. Sadly, insufficient and inefficient power generation facilities, poor maintenance of long transmission lines and distribution facilities are some of the problems facing the electricity sector [13,12]. Although, Akinbami [7] highlighted some of the problems facing renewable energy development in Nigeria as technological incapability, high cost of energy, financial constraint and low level of public awareness, the level of development witnessed so far, reflects the country's resilience and ability to adopt the technologies as part of its energy mix. It is on this note that [3] recommended that private partnership agreement, investments in research and development, and government incentives should be backed by policies in order to encourage investments in these technologies.

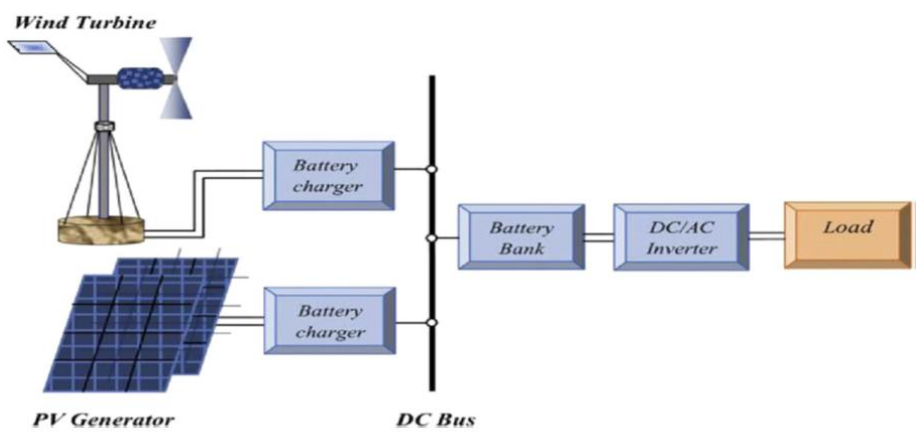


Fig. 1. Hybrid PV/Wind system [5]

Table 1. Rural electrification projects in Nigeria using renewable energy sources

Project type	Location	Rating in kW	Energy source
Village electrification	Sayya Gidan Gada, Sokoto	5	Wind
Village electrification	Durumi, Surburb of Abuja	3	Solar
Village electrification	Kwalkwalawa, Sokoto	7.2	Solar
Campus electrification	University, Sokoto	1.5	Solar
Internet back-up	Nunet, University, Sokoto	2	Solar
School electrification	Kaduna	5	Solar
Communication & electrification	Mechanized Brigade, Kano	1	Solar
Communication & electrification	Kaduna	1.5	Solar
Street lighting	Uyo, Cross River	–	Solar
Electrification	Ganjuma, Bauchi	150	SHP
Electrification	Enugu	30	SHP
Electrification	Kakara, Sarduna, Taraba	400	SHP
Electrification (ongoing project)	Benue	435	SHP

Source: [8].

2.3 Environmental Impact of HRES

Aliyu et al. [3] posits that environmental consequences of energy systems are enormous and can disrupt the ecosystem. However, renewable energy sources in Nigeria are limitless and environmentally friendly, which could serve as solution to insufficient energy available to Nigerians and also lead to cleaner environment. The major drivers of renewable energy in Nigeria should be lack of constant energy supply and the need to curb excessive emission of greenhouse gases. Renewable sources of energy are known to reduce greenhouse gas emissions, thereby seeking to substitute fossil fuel as the main source of electricity generation in the world [8]. Thus, numerous researches have been conducted to measure the amount of CO_2 achieved by introducing renewable energy technologies.

The emission from a diesel generator is much higher than the emission from a PV [14], as a result of fossil fuel consumption by diesel generators. The use of distributed energy resources promises clean and cost-efficient energy than diesel-based generators; hence, PV technology will deliver clean, more efficient and reliable electricity at a cheaper cost than diesel generator or fossil fuel-based power plant in Nigeria [8]. Consequently, promoting the development of renewable energy would help to prevent the country from falling into a “fossil fuel trap” [7], a situation where the energy sector is heavily dependent on fossil sources to meet the need of its citizens. The author further posited that renewable energy technologies would help to solve some ecological problems of deforestation, greenhouse gas emissions and the curtailment of soil erosion. Adoption of PV system will help reduce internal consumption of petroleum products in rural communities because of the simplicity of PV technologies, ease of maintenance and environmental friendliness over fossil fuels [15].

Olatomiwa et al. [4] posits that the hybrid renewable energy system which comprises a diesel generator emits less CO_2 than diesel generators, and is better than diesel only system in terms of reduced cost, quality of electricity supply and fuel consumption. Smart-grid technologies tend to reduce over dependence on the national grid thereby reducing the frequency of its breakdown [8].

In the light of the foregoing, the government and other private organizations, in their attempt to solve one of United Nation’s Sustainable Development Goals (SDG) of adequate access to energy, should adopt hybrid renewable energy systems in providing clean and non-depleting renewable energy to people living in rural areas [16]. Furthermore, there is a need for urgent development of a road map for smart-grid technologies in Nigeria [8].

2.4 Empirical Review

Extensive studies have been conducted by researchers to assess the techno-economic viability of stand-alone renewable energy technologies (RETs), hybrid energy systems (HES) and hybrid renewable energy systems (HRES) in Nigeria using different techniques. Oseni [13] conducted a critical evaluation of Nigeria’s power sector, measuring its performance vis-à-vis Nigeria’s economic performance. The study suggested that renewable energy should be adequately harnessed to solve the problem of inadequate electricity supply in the country. Adeyanju and Manoher [15] assessed solar energy technologies in Nigeria. The study recommended that more research needs to be done to increase the utilization of solar energy in Nigeria.

Vincent and Yusuf [12] made a case for the adoption of RETs as part of Nigeria’s energy mix. The study concluded that integration of smart grid technologies and renewable energy into the country’s energy mix is the only solution to Nigeria’s electricity problem. Aliyu et al. [3] examined the current status and future prospects of RETs for Nigeria. The study concluded that enhancing the utilization of renewable energy technologies would boost electricity supply in Nigeria.

Adaramola et al. [9] evaluated the performance of wind turbines for electricity generation in seven (7) communities located in the Niger-Delta region of Nigeria using 2-parameter Weibull Distribution functions to evaluate wind speed data over a period of 9 to 35 years. The outcome of the analysis showed that wind energy in the Delta region is not suitable for large scale electricity generation. Rather, a wind turbine will be more efficient in a small-scale application like battery charging and water pumping. Its optimum performance would be obtained if it is part of a hybrid renewable energy system.

Offiong [14] conducted an economic evaluation of solar PV and diesel generator for stand-by electricity supply by comparing its life expectancy, capital cost, maintenance cost per annum, fuel cost per annum and annual cost of energy. The outcome of the study revealed that the cost of running a diesel generator is higher than the cost of installing and maintaining a solar PV system.

Other researchers have adopted the Hybrid Optimization Model for Electric Renewable (HOMER) simulation tool which was developed by the United States National Renewable Energy Laboratory (NREL) under the Department of Energy in examining the techno-economic viability of hybrid systems. The economic indicators of the HOMER simulation tools are net present cost (NPC), cost of energy (COE), renewable fraction (RF) and CO_2 emission. This simulation tool has been adopted by Ileberi et al. [10] to examine hybrid energy systems composed of grid-only, grid-solar-wind and grid-solar-wind-diesel generator for energy supply to meet the demand of the Centre for Satellite Technology and Development building in Abuja, Nigeria. The outcome of the study revealed that the grid supply is the cheapest source of electricity and the penetration of renewable energy led to the fall of about 61% in grid supply.

Ajayi et al. [16] adopted the HOMER in conducting an economic analysis of utilizing RETs for rural electrification and embedded power generation for six (6) sites in the North-East region of Nigeria by assessing the feasibility and economic viability of wind and solar energy technologies in providing off-grid electricity to rural areas. The study considered three stand-alone designs which consists of PV, wind and diesel system, and a hybrid system of wind-PV. The outcome of the analysis showed that the hybrid energy system is more viable than the other options in 5 out of the 6 locations (Potiskum, Nguru, Bauchi, Ibi and Yola), while the standalone wind technology is the most optimum energy technology in the last region (Maiduguri).

Olatomiwa et al. [4] adopted the HOMER simulation tool to determine the feasibility of hybrid energy system comprising solar-wind-diesel generator in six (6) rural communities selected from each of the six (6) geo-political zones in Nigeria. The study examined seven different configurations of stand-alone diesel only system, PV-diesel, PV-diesel-battery, wind-diesel, wind-diesel-battery, PV-wind-diesel and PV-wind-diesel-battery. The outcome of the study revealed that the PV-diesel-battery hybrid system is the most optimum system and it can be obtained when installed in Tambo village in the tropical dry climate zone of Nigeria.

In the same vein, several other countries have conducted studies on hybrid energy systems using HOMER. For instance, Shezan et al. [17] carried out the techno-economic analysis of hybrid solar-wind-diesel generator for rural off-grid communities of Brisbane, Australia using HOMER. The study concluded that the hybrid renewable energy system is more economically viable and environmentally friendly when compared to other conventional means of energy.

Some authors have conducted studies to evaluate the techno-economic viability of HRES using other methods. The study conducted by Okundamiya et al. [11] adopted the genetic algorithm-based technique for optimal sizing of hybrid renewable energy system component of solar-wind in order to effectively meet the load demand of telecommunication networks. The study suggested a grid-connected hybrid system comprising of PV-wind technologies. Akinbami [7] employed the multi-period linear programming optimization model called MARKAL (Market Allocation) developed by Fishbone et al. [18] in analyzing the future prospects of renewable energy in Nigeria's economy. The study concluded that renewable energy is important in increasing electricity supply in Nigeria. The study therefore suggested the establishment of a national agency for renewable energy systems in Nigeria.

The review of past literature has revealed the level of research conducted so far on hybrid energy systems in Nigeria and other countries of the world. However, none of them has been able to make a case for economic viability of HRES in Nigeria by modelling the Renewable Energy Feed-In Tariff (REFIT) developed by the Nigerian Electricity Regulatory Commission (NERC) using the discounted cash flow methodology. This study aims to fill this gap that exists in literature.

3. METHODOLOGY

This study conducts economic evaluation of HRES by modelling Nigeria's renewable energy according to the guidelines set out by NERC under the framework of the REFIT. REFIT contains the plant specification, maximum allowable capacity and benchmark capital and operating costs of the different types of renewable energy technologies available in Nigeria. It also contains the method of computing the feed-in tariff for renewable energy technologies targeted at the national grid. The fiscal framework for the evaluation is based on the Company Income Tax Act (CITA).

In evaluating the HRES, this paper developed three (3) different economic models. The first and second models were developed for evaluating independent RET projects viz: solar PV and wind technology while the third model was developed for evaluating the HRES. This study adopts the discounted cash flow methodology (DCF) as set out by Mian [19] in conducting the economic evaluation of the 3 projects. The analyses for the independent technologies were benchmarked against the Feed-In tariffs as shown in table 4 to determine the viability of each RE source independently. Thereafter, the HRES was evaluated using an optimized mix of solar PV and wind system.

3.1 Formulation of Model

This study developed three (3) economic models using the DCF methodology for project evaluation. This method was adopted in order to ensure proper and thorough evaluation of the renewable energy project, while at the same time account for the time value of money [20]. The method is widely used, and is accepted worldwide as a good method for evaluating projects. The approach used is as set out by Mian [19] and adopted by Falode and Ladeinde [20]. The net present value (NPV), internal rate of return (IRR), payout period, present value ratio (PVP) and maximum cash in red (MCR) are the economic indicators that will be used in analyzing the viability of the project.

3.2 Data Source

The data used in this study were obtained from the REFIT and the CITA.

3.3 Model Assumptions

The assumptions used in building the models are mainly based on the REFIT designed by NERC.

The assumptions of the models are specified in Table 2 to Table 4.

4. DISCUSSION OF RESULTS

4.1 Independent Models

Based on the assumptions set out in Tables 2 and 4, economic analysis was carried out for the wind and solar PV projects as independent projects. The result of the analyses is presented in Table 5. Both projects have positive NPVs amidst other parameters which indicate that value benefits exist if projects are executed. Overall, project indicators as shown in Table 5 reveal the wind project as a more viable project at its benchmark tariff of $136/MWh compared to the solar project at an even higher benchmark tariff of $192/MWh.

Table 2. General assumptions – RETs

Description	Unit	Solar	Wind
Capacity	MW	5	5
Capital Cost	$/kW	1500	1760
Capacity Utilization factor	%	19%	32%
Fixed O&M	$/kW/yr	30.00	18.50
Variable O&M	$/MWh	0.06	1.48
Auxiliary Power requirement	%	1	1
Construction time	Year	2	2
Exchange rate (₦ to $)	Naira	200	200
Real WACC	%	11	11
Local Inflation	%	8.3	8.3

Table 3. General assumptions – HRES

Description	Unit	
Hybrid Type		Wind – Solar PV
Capacity	MW	5
Energy Mix		50%/50%

Table 4. REFIT benchmark

NERC FIT Benchmark	Unit	Wind		Solar	
		$ 2016	$ 2020	$ 2016	$ 2020
Capital Cost	₦/MWh	24,791.55		35,370.05	
O&M	₦/MWh	302.73	416.46	29.49	40.57
Total	₦/MWh	25,094.28		35,399.54	
Capital Cost	$/MWh	123.96	134.18	176.85	191.43
O&M	$/MWh	1.51		0.15	
Total	$/MWh	125.47		177.00	
Benchmark FIT ($/MWh)			**136.26**		**191.63**

Note: ₦/MWh represents Nigerian Naira per megawatt hour, while $/MWh represents US Dollars per megawatt hour

Table 5. Renewable energy technology project indicators

Project Indicators	Unit	Wind	Solar
Total Revenue	$m	45.9	19.1
Net Cash Flow	$m	20.8	7.9
NPV at WACC	$m	1.2	0.1
IRR		12.4%	11.2%
Pay-out	years	9	10

Note: $m represents million US Dollars

On this basis, one can be quick to focus attention on wind projects for higher returns. However, there exists other bottlenecks that requires an investor's attention before making an investment decision. Sustainability of supply is one of such bottlenecks as wind is not readily available all year round. This brings to bear considerations for HRES which can resolve the bottlenecks by adopting more than one RETs and target a competitive landing power tariff. The HRES evaluation is shown in subsequent sections.

4.2 Cash Flow Analysis of HRES

Economic analysis shows a total revenue of about $42m over the 20-year life cycle. As shown in Fig. 2, the first two years of the project will generate a negative cash flow as this period is

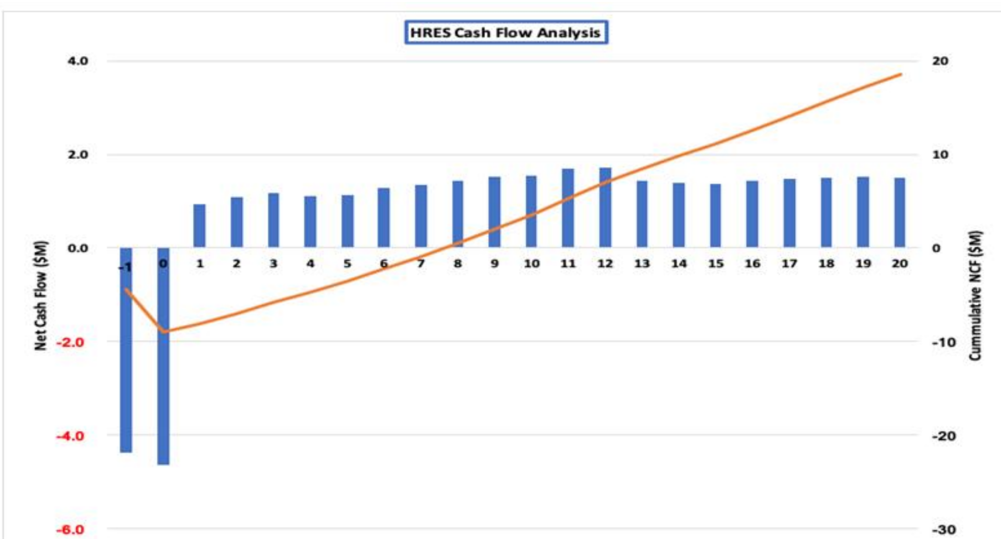


Fig. 2. Cash flow analysis of the project

the construction phase of the project before commencement of operations the following year. The NCF after deduction of all running costs and other obligatory charges amounts to about $19m within the same period at an average of $1.4m annually.

4.3 Profitability Analysis of HRES

The economic parameters resulting from the HRES project evaluation is presented in Table 6. At a target IRR of 12% which aligns with the results of the independent models and taken as a fair return, the HRES project has a positive NPV of US$0.8m when discounted at WACC. This indicates that the system provides value benefits. Also, the power tariff required to achieve the target IRR is about $157/MWh. This shows that the HRES project is viable at a tariff less than the REFIT benchmark for stand-alone solar projects.

In addition, the Profitability Index (PI) which shows the profit to investment ratio is 1.1, indicates that the project is profitable as the decision rule for profitability in theory favours projects with PI>1. Unit technical cost of the HRES, which stands at $106.7/MWh, is lower than the computed power tariff. This shows that the project is able to declare profit after attending to all associated cost parameters. Hence, the system is profitable.

The total direct investment as shown by the Maximum Cash in Red (MCR) of $9m indicates the maximum cash flow exposure during the life cycle of the HRES project. It takes a period of 10 years, that is, 7 years post commencement of operations for the project to breakeven and payout capital investment.

Overall, the result of this economic analysis suggests that HRES can be profitable in Nigeria given the present regulatory framework and fiscal incentives put in place by the Nigerian government to regulate and encourage investments in renewable energy. However, power tariff must be carefully compared to NERC benchmarks.

4.4 Analysis of HRES Power Tariff

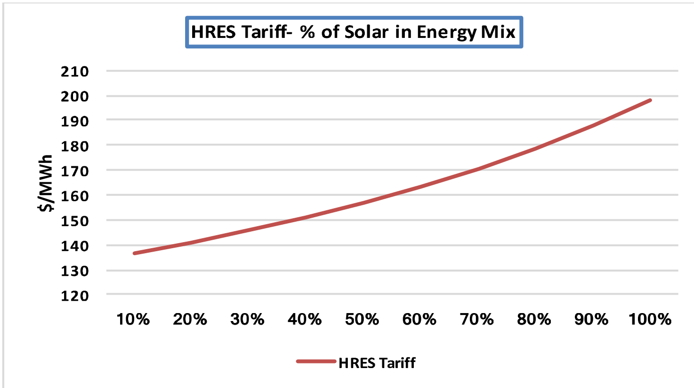
One major determinant of the profitability of HRES projects is the power tariff. The power tariff generated by the economic analysis carried out in this study is $156.9/MWh. This tariff is lower than that charged per MWh of energy generated by solar PV ($191.63/MWh) and slightly higher than the tariff charged per MWh of wind turbine ($136.26/MWh) according to NERC REFIT benchmark as shown in Table 4.

Fig. 3 presents the percentage contribution of solar PV in the HRES vis-a-vis the tariff per MWh of power generated by the system. This figure indicates optimal energy mix for the HRES project. The trend shows an accelerated upward percentage change in HRES tariff when the contribution of solar power to the energy mix is above 50%. As indicated earlier in the study, solar PV as an independent project compared to a wind system is challenged in 2 fronts viz: higher power generation tariff and lower investment returns. These challenges can make wind projects generally more attractive.

However, for long term plans and sustainability of investments, HRES requires some solar generation in its energy mix and the resultant effect is shown in Fig. 3. Clearly, the HRES project requires not more than a 50% contribution from solar PV as anything higher clearly puts solar in the driving seat of tariff determination and the impact is felt more rapidly by the final HRES tariff.

Table 6. Economic analysis result

Indicators	Unit	Value
Power Tariff	*$/MWh*	156.9
Unit Technical cost	*$/MWh*	106.7
NCF	*$m*	18.6
NPV at WACC	*$m*	0.8
IRR	%	12%
PI	%	1.1
MCR	*$m*	-9.0
Payout	*years*	9



Solar % of mix	HRES Tariff
10%	136.68
20%	141.12
30%	145.83
40%	151.11
50%	156.90
60%	163.31
70%	170.44
80%	178.43
90%	187.45
100%	197.76

Fig. 3. HRES tariff assessment

5. CONCLUSION AND RECOMMENDATIONS

This study takes a look at the technological readiness of Nigeria to adopt the hybrid solar PV-wind energy system, its environmental impact and its profitability. The outcome of the paper review conducted in this study suggests that Nigeria has huge renewable energy potentials, and given that the country already has independent renewable energy projects across the country, hybrid renewable energy system is another option to consider. Also, HRES would help reduce CO_2 emission from fossil fuel [diesel] power plants thereby protecting the climate from further damage. The outcome of the economic evaluation of HRES revealed that HRES is profitable given existing regulatory and fiscal framework set out by the Nigerian government. Furthermore, the energy tariff charged per MW of power generated by HRES is cheaper than the energy tariff per MW charged by solar PV system.

Based on the foregoing, this study recommends that investors in renewable energy projects in Nigeria should consider constructing the HRES for power generation as against the construction of a single renewable energy technology. The HRES maximizes output at the lowest minimum cost and it is more economical than single system renewable energy projects. Also, this study recommends that the REFIT regulations should be reviewed in order for the policy to reflect the current realities in the Nigerian economy.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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