Feasibility and Econometrics Assessment of Standalone and Hybrid RE Facilities for Rural Community Utilization and Embedded Generation in North-West, Nigeria

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Abstract—**This study assessed the feasibility and economic viability of renewable energy resources for power generation at rural communities of six sites in North-West Nigeria. A specific electric load profile was developed to suite the rural communities made up of 200 homes, a school and health centre. The required load was analysed as 358 kWh per day, with 46 kW primary peak load and 20 kW deferrable peak load. The employed data obtained from the Nigeria Meteorological Department, were those of daily mean wind speeds, daily global solar radiation, sunshine hours, minimum and maximum air temperature, and minimum and maximum relative humidity for 24 years spanning 1987-2010. The assessment of the design that will optimally meet the daily load demand with LOLP of 0.01 was carried out by considering 3 standalone applications of PV, Wind and Diesel, and a hybrid design of Wind-PV. The outcome showed that the most economically viable alternative for power generation at the different locations in Gusau, Kaduna and Yelwa was the hybrid system while wind standalone suffices for the other sites. The values of LCOE for the both the hybrid and standalone wind system are competitive with grid electricity. .**

***Index Terms*— Photovoltaic Power; Wind power; Solar-Wind Hybrid; Cost per kWh; Clean Energy; Northwest-Nigeria**

I. INTRODUCTION

Amongst the array of troubles facing the global environment, a common agreement is that greenhouse gas (GHG) emissions have the greatest negative consequence on the ecosystem [1]. GHGs comprise methane, carbon dioxide, hydro fluorocarbons, nitrous oxide, sulphur hexafluoride, and per fluorocarbons [2]. These gases aid in maintaining the temperature of the earth at reasonable levels for survival of organisms, a decline in their amounts could lead to temperatures becoming too low for our survival. Conversely, GHGs permit sunlight to penetrate the atmosphere, but entrap the heat radiated off the earth's surface. An increment in these emissions therefore would result in an amplification of the earth's temperature (global warming), to levels that could be terminal to living organisms. Many scientists accept that the increase in natural disasters is fired by climate change, because atmospheric and oceanic patterns shift as the earth's temperature rises [1- 4].

The Kyoto protocol, a part of the United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty that sets obligatory commitments on industrialized nations to diminish GHG emissions. It has the objective of avoiding anthropogenic disturbance of the ecosystem [5]. Developing nations do not have obligatory targets under the Kyoto Protocol, but are still bound under the treaty to decrease their emissions [4]. Measures taken by developed and developing nations to diminish emissions include support for renewable energy, enhancing energy efficiency, and limiting deforestation [6]. The protocol introduced three mechanisms in order to assist economies in meeting their emissions' limitations. These include the Joint Implementation Mechanism that permits nations to carry out emissions reduction projects in other countries so as to earn emission credits. Another involves the Clean Development Mechanism that encourages nations to grow emissions credits by financing emissions reduction projects in developing countries. The third is the Emissions Trading (carbon trading). It offers an incentive for governments and companies to diminish their emissions [7].

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The financial inducements, as well as carbon-emission restrictions, are not the only factors driving governments along the path of renewable and clean energy. The shortage of fossil fuels and their speedy depletion has made it globally imperative to explore alternative sources of energy that would match increasing levels of demand. Also, much of the world's populace resides in remote or rural areas, which are thinly populated and geographically isolated [8]. Owing to their low energy demand, poverty and geographical isolation, such regions remain unconnected to the national grid. But to develop such areas, an effective and fiscally viable system is needed so as to provide these regions with electricity. The proposition among many researchers is that renewable energy sources should be well-matched towards this goal [9-16]. Therefore renewable energy sources such as solar energy and wind energy which have been considered clean, infinite, and ecologically friendly [16], have drawn the energy sector towards the use on a prominent scale [17].

Nonetheless, all renewable energy sources have shortcomings. The most common for wind and solar sources is their reliance on weather and climatic conditions. Propitiously, as a result of the balancing nature of both sources, the unpredictable nature of these sources is addressed by surmounting the weaknesses of one with the strengths of the other [17]. This has brought about the concept of solar-wind hybrid power plant. Consequently hybrid renewable energy systems have been on the increase for remote area power generation applications due to growth in renewable energy technologies and also a rise in prices of petroleum products [16]. A hybrid energy system (HES) typically is made up of two or more renewable energy sources integrated together to enhance system efficiency. HES are also designed in order to maximize the use of renewable resources in a mix with conventional sources ensuing in a system with lower emissions than traditional standalone fossil-fuelled technologies. Hence hybrid energy plants have been proved to be profitable in reducing the depletion rate of fossil fuels, as well as furnishing remote rural areas with energy [18]. Therefore, a solar-wind energy system taking advantage of the complementary profiles of both energy sources would seem to be a feasible idea. However, there remains a complexity brought about by the combination of two different energy sources making hybrid systems more difficult to analyse.

II. REVIEW OF SOME EXISTING STUDIES

In Nigeria very few research studies exist that have assessed the potential of hybrid RE system for power generation [19 – 22]. Despite this, the available results focused on small scale generation for remote telecom applications and also for individual buildings. Research reports on design and economic feasibility of hybrid systems that can provide sustainable power for rural communities are scarce both in Nigeria and around the globe. Based on the previous studies, most studies were focused on researches into optimization for specific locations without a focus on a community wide analysis that specifically determined the technical and econometric results. Most of the analysis did not also consider the effects of other variables on the PV system such as relative humidity, air temperature, atmospheric pressure and wind speed as is captured using the RETScreen® software. Also the role of battery and the level of reliability in terms of Loss of Load Probability (LOLP) were ignored by many of the reports. This makes the reports more of scientific approaches towards the feasibility analysis rather than a technical report that could serve as a tool for government and investors to establish various RE projects in any of these locations.

This study is therefore focused on the assessment of the potential and economic viability of standalone and embedded power generation in six selected rural communities of North-West, Nigeria. The six sites are spread across six (of the seven) states of the North-West geopolitical zone of Nigeria. Rural communities made up of 200 homes, a school and health centre was conceived for each site.

III.. MATERIALS AND METHOD

A Data Collection

The twenty-four years (1987 – 2010) daily global solar radiation, daily wind speed data, sunshine hours, minimum and maximum air temperature, and minimum and maximum relative humidity that were employed for this study were sourced from the Nigeria Meteorological agency (NIMET), Oshodi, Lagos, Nigeria. The location parameters of the selected sites are as shown in Table 1. Wind turbines ranging from two to five

25 kW turbines, with single 3MW turbines for embedded generation, cumulative solar panels ranging between 105 kW & 140 kW with 7.5MW for embedded generation, and a diesel generator of 35 kW were employed for the study as standalone or hybrid power systems. The econometric analysis of the diesel system for comparison is presented in Table 2. The average air temperature and relative humidity were included in the RETScreen® analysis because of the dependence of PV module efficiency on surrounding air temperature and relative humidity. The efficiency of photovoltaic cells has been found to fluctuate with their operating temperature [23-26] as most cell types demonstrate a decline in efficiency as their temperature rises, while it was also found that increased relative humidity acts to diminish the amount of visible solar radiation retrievable [27-29], and also together with magnitude of wind speed acts as cooling agents that boost the output of a PV module by dipping the module temperature [27].

B. Load calculation

The load profiles of rural communities is not easily assumable, but can be considered to be very low when compared to urban communities. It is reported that an average of 1 kWh/day per home can be associated with rural community homes [30 – 31]. However, for the purpose of this study, the energy demand requirement of the rural communities were assumed to be based on the individual power rating of the appliances utilized in each home.

C. PV Array Optimization Modelling

This was carried out by using the Hybrid Optimization Model for Electric Renewable (HOMER®). The model of Duffie and Beckmann [34] was used by HOMER® in calculating the global solar radiation incident on the PV array for each hour of the year.

D. Cost benefit analysis

Economics plays a pivotal role in the selection of the best combination of energy resources, since renewable and non-renewable energy sources typically have radically dissimilar cost characteristics. Renewable sources lean towards high initial capital costs but low operating costs, while conventional non-renewable sources usually tend to be vice versa in terms of capital and operating costs. Hence the optimization process by HOMER® is performed in a way as to diminish total net present cost (NPC) of the analysed system [37]. The NPC is same as the net present value (NPV) in magnitude, but with an opposite sign, i.e. negative NPC equates to a positive NPV. The annualized costs for each component of the RE system analysed, together with any miscellaneous costs is used to find the total annualized cost of the system. The total net present cost is therefore:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, R_{proj})} \quad (1)$$

where $C_{ann,tot}$ = total annualized cost, i, the annual real interest rate (the discount rate), R_{proj} the project lifetime, and CRF(•) is the capital recovery factor, given by the equation:

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (2)$$

where, i is the annual real interest rate and N is the number of years.

The levelized cost of energy (LCOE) is:

$$LCOE = \frac{C_{ann,tot}}{E_{prim} + E_{def} + E_{grid,sales}} \quad (3)$$

Where $C_{ann,tot}$ is the total annualized cost, E_{prim} and E_{def} are the total amounts of primary and deferrable load, respectively, that the system serves per year, and $E_{grid,sales}$ is the amount of energy sold to the grid per year.

III. RESULTS AND DISCUSSION

Fig. 2 presents the average monthly solar radiation profiles covering the period between 1987 and 2010. The figure shows that the 24 years' monthly average solar radiation ranged between 4.03 (kWh/m²/d) in August for Gusau and 6.701 (kWh/m²/d) in April for Yelwa. Fig. 2 also shows that the period between July and August experiences the least solar radiation across the sites/states. Kano and Katsina appear to be the sites/states with the better solar profiles and Gusau and Yelwa with the worst. Considering the hours equalled or exceeded for a series of mean measured solar radiation across the studied period revealed that the power generated for each site from the designed PV array is between 4690 hours for Gusau and 4744 hours for Kano out of the 8760 hours in a year. This corresponds to about 53.5% - 54.1% of the hourly duration in a whole year. This however is because solar radiation, unlike wind speed, is in occurrence only during the daytime with Gusau having a twenty-four years' average sunshine daily duration of about 6.72 hours, while Kano has 7.85 hours. Fig. 2 thus

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proves that the solar radiation profiles for all sites in North West Nigeria are very similar which can also be adduced to be associated with the geographical homogeneity. The correlation of the annual average solar radiation and PV module size for the 6 sites is presented in Fig. 2. It demonstrates that a good correlation exists between the incident irradiation and the PV size. An inverse proportionality exists between the two quantities, with the PV requirement increasing with reduction in solar radiation intensity. This is due to the overriding influence of daily global solar radiation on the sizing of photovoltaic systems. It also shows that the 24 years' annual average solar radiation ranged between 5.003 (kWh/m². day) for Gusau and 6.008 (kWh/m². day) in Kano with a corresponding PV rating of 140 kW and 105 kW respectively.

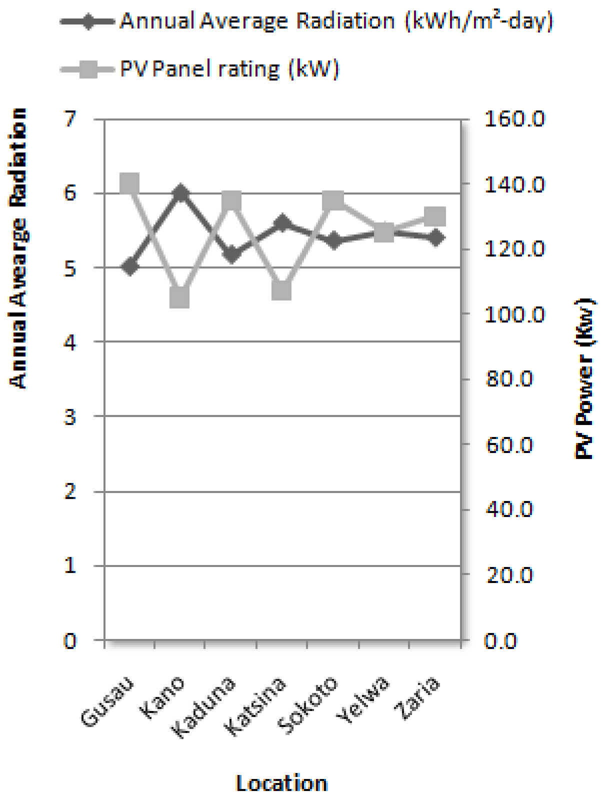

Fig 1: Correlation between the monthly average solar radiation and solar panel size for north-west Nigeria

The battery days of autonomy ranged between 48.7 hours for Kano and 63.9 hours for Yelwa at an initial state of charge of 50%. Thence, with a design covering an entire year, it gives rise to an excess in energy generated annually when the period of higher sunshine duration is balanced with those of lower duration. The excess may be utilized in the form of embedded generation. Moreover, embedded generation is a form of generation where excess renewable energy generated by a consumer within a certain range can be sold to a nearby distribution network The sales to the grid have the benefit of a reduction in the LCOE, as indicated by equation 3. Though the excess may not always be eliminated (or sold to the grid) as it will be wasted when less than 1 MW if optimum battery capacity by design could not take care of this excess. The analysis reveals that the effect of solar panel on the total NPC is averagely about 52% for the north-west region, while 42% is related to battery's initial, maintenance and replacement costs with the remaining borne by the converter. With the present rate of decline in prices of solar panels, therefore, the effect on life cycle cost will progressively decline which will make PV systems much more competitive with grid electricity. Fig. 3 also makes a comparison between total NPC and initial capital cost and reveals that both costs follow the same pattern, which is due to all sites using the same technology, though the initial costs are less than NPC for each site.

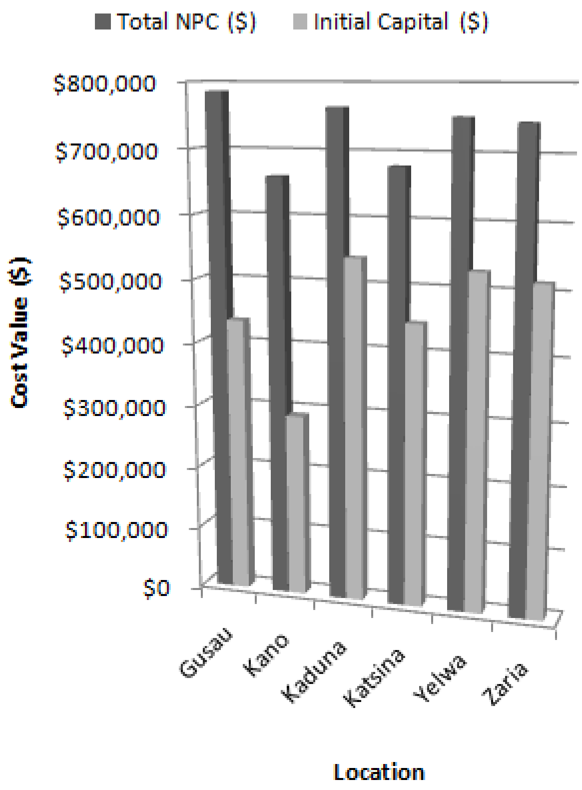

Fig 2: Comparison between Net Present Cost (NPC) and Initial Capital for PV standalone system

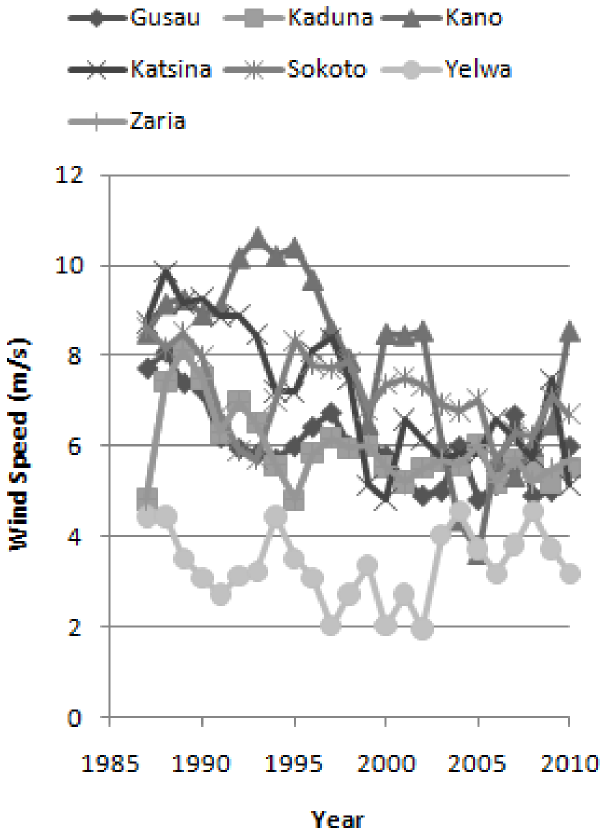

Fig. 3: Plot of 24 Years' Annual Average Wind Speeds

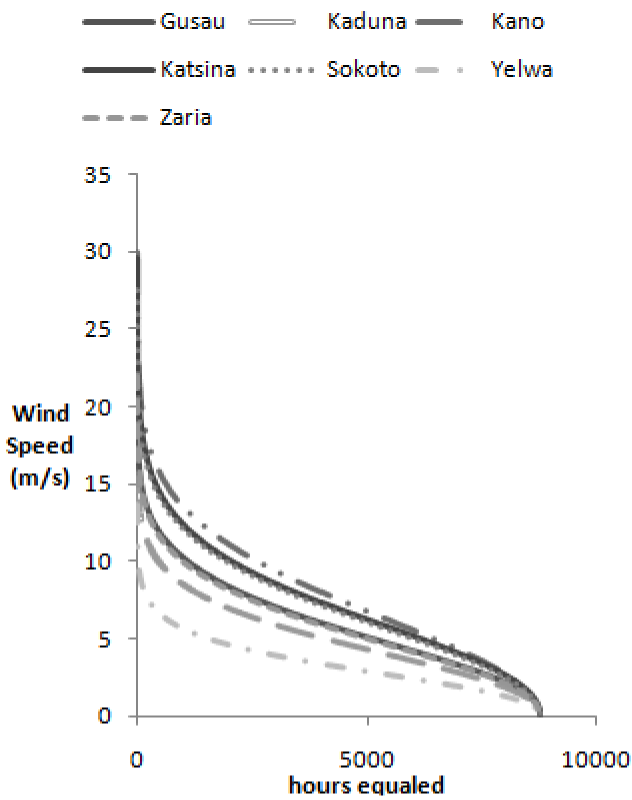

Fig. 4: Plot of 24 Years' Annual Average Hours Equaled or Exceeded for different wind speeds

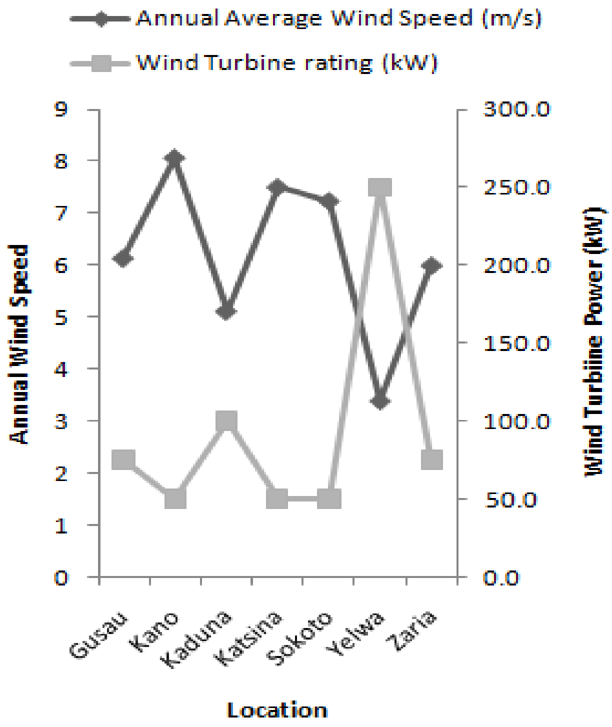

Fig 5: Correlation between the monthly wind speed and wind turbine capacity

The analysis further revealed an average excess electricity equivalent to 61% of annual generation. This is because wind power is generated for about 85% of the time in North-West, Nigeria Therefore since the sites have the ability of generation for over two-thirds of every hour of the day, an average optimal battery size of 33.5 hours of autonomy can be employed. Also since the rated speed for the PGE 20/25 turbines used in the design is 9 m/s, The total NPC was found to be averagely 24% less for the WSS than the total NPC for the PSS when all sites were considered. It was also observed that the greatest differential of NPC by cost type is with the capital cost. The capital cost for the WSS is 70% less than that of the PSS. Also, the cost of replacement, operating cost, and the salvage value were lower by about 51%, 36%, and 32%, respectively.

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