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Original Research Article

Assessment of Wind-Solar Resource Potentials and Optimization Analysis of Wind-Solar Hybrid Energy System Across Selected Locations in Kebbi State, Nigeria

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Abstract

Kebbi state is a region in Northern Nigeria blessed with reasonable resources potentials of both solar and wind energy, but faced with lot of crises of energy supply and distributions due to improper distribution network as results of systems collapse and inadequate utilization of the renewable energy resources such as wind and Solar. This study assesses wind and solar resources in three selected locations of Kebbi state (Argungu, Jega, and Yauri) from the three different senatorial districts across the state using NASA POWER data from 2000 to 2022 and the HOMER optimisation tool, a hybrid renewable system was created for a rural community. The goal was to keep the Net Present Cost (NPC) and Levelized Cost of Energy (LCOE) as low as possible while keeping the capacity deficit below 1%. The solar resource assessment shows a lot of promise. The average global horizontal irradiance ranges from 4.80 to 5.68 kWh/m²/day in Yauri and from 5.30 to 5.88 kWh/m²/day in Argungu and Jega 5.30 to 5.88 kWh/m²/day in Argungu and Jega. The wind resources are not too good, average speeds at 50 m height are between 2.83 and 3.17 m/s for all the selected locations. The results of the optimisation show that a PV-battery-converter hybrid system being the best option for all the selected locations. Wind turbines aren't the best because they don't work well in low wind speeds. The study revealed that solar PV-battery systems are a technically feasible and cost-effective way to deploy electricity to rural areas in Kebbi State. This gives policymakers and investors a data-driven way to use decentralized renewable energy as compliment to the national grid.

Keywords: Renewable energy, Hybrid energy system, HOMER, Net present cost and Levelized cost of energy.

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1. INTRODUCTION

The global energy landscape is undergoing a profound transformation driven by the imperatives of climate change mitigation, energy security, and sustainable development. As conventional fossil fuel reserves dwindle and their environmental externalities become increasingly untenable, renewable energy sources have emerged as viable alternatives for electricity generation [1]. This transition is particularly critical for developing nations like Nigeria, where energy access deficits constrain economic growth and social development. Despite being Africa's largest economy and possessing abundant energy resources, Nigeria continues to grapple with significant electricity access challenges, particularly in rural areas where only 43% of the population has moderate electricity access compared to 90% in urban centres [2; 3].

Access to reliable and affordable power is a critical component of socioeconomic growth. Despite being Africa's largest economy and having tremendous energy resources, Nigeria is experiencing a severe electrical problem. The national system is plagued by inadequacies, frequent failures, and an inability to satisfy peak demand, leaving millions of people, particularly in rural regions, without access to power [4]. This energy poverty suppresses economic activity, impedes educational advancement, and jeopardizes healthcare services. Kebbi State, located in Nigeria's North-Western area, is primarily agricultural and highly reliant on the national grid, which is infamously unstable. The state's reliance on hydroelectric electricity from the Kainji and Jebba dams makes it especially vulnerable to periodic variations in water levels, resulting in frequent blackouts during the dry season. This precarious position needs a rapid transition to decentralized, resilient, and sustainable energy solutions. Northern Nigeria, including Kebbi State, is endowed with substantial renewable energy resources that remain largely untapped. The region receives some of the highest solar radiation levels in the country, averaging above 21 MJ/m²/day, making it exceptionally suitable for photovoltaic (PV) power generation [5].

Additionally, recent assessments have identified significant wind energy potential in states including Kebbi, Katsina, and Sokoto, with wind resources exhibiting strong seasonal patterns that complement solar availability [1]. This complementary characteristic makes hybrid wind-solar systems particularly attractive for ensuring reliable year-round electricity supply. Three senatorial districts with a variety of physical and climatic features make up Kebbi State, which is situated in Nigeria's northwest. The state has recently drawn large investments in renewable energy, like as a $120 million 100 MW off-grid solar power facility, establishing it as a developing center for clean energy development in the northwest of Nigeria [6]. Nevertheless, there is still a dearth of research on the optimization study of hybrid systems for these particular sites and the systematic evaluation of wind-solar resource potentials throughout the three senatorial districts. This literature review examines the current state of knowledge regarding wind and solar resource assessment methodologies, hybrid renewable energy system optimization techniques, and applications relevant to Kebbi State, Nigeria. The demands of energy security, sustainable growth, and climate change mitigation are causing a significant shift in the world's energy landscape. Renewable energy sources have become feasible options for producing power as traditional fossil fuel supplies deplete and their environmental externalities become more intolerable [7]. For developing countries like Nigeria, where inadequate energy access limits social and economic development, this shift is especially crucial. Nigeria still has serious problems with electricity access, especially in rural areas where only 43% of the population has moderate electricity access compared to 90% in urban centers, despite having the largest economy in Africa and an abundance of energy resources [2;3].

Kebbi State's principal energy concern is a severe lack of grid reliability, as well as the high expense of connecting isolated rural villages to the national grid. The alternative diesel or gasoline generators is not only monetarily prohibitive for many due to high fuel and maintenance expenses, but also environmentally harmful. While the region is located in Nigeria's high-solar belt, there is a lack of a comprehensive and location-specific assessment of its renewable energy potential, notably the synergy between solar and wind. Without such data-driven research, planning and investment in hybrid energy systems are risky and suboptimal. Geographic Information Systems (GIS) have become indispensable tools for renewable energy resource assessment, enabling spatial visualization and multi-criteria analysis of suitable locations for system deployment.

[8] demonstrated the application of GIS-based suitability analysis for hybrid renewable energy systems in rural areas of Abuja, integrating environmental, topographic, and socio-economic criteria including solar irradiance, wind speed, and land use patterns. The weighted overlay method, a Multi-Criteria Decision Analysis (MCDA) technique, combines multiple spatial layers to identify optimal locations [9]. In the Federal Capital Territory [9] applied GIS-based assessment to evaluate solar, wind, and biomass resources where he recorded solar irradiation values between 1853.4 and 1936.8 kWh/m²/year across different area councils.

Wind speeds were generally very low with monthly average between 1.63 – 1.83 m/s at 10 m height across the state, highlighting the importance of site-specific assessment for wind energy development. For Kebbi State, such spatially explicit resource assessments across the three senatorial districts remain absent from the literature, representing a significant research gap that the present study addresses. To address the intermittency and variability issues with single-source renewable energy systems, hybrid renewable energy systems (HRES) combine many energy sources [10]. Photovoltaic panels, wind turbines, and battery storage make up the most popular off-grid arrangement; for further dependability, a backup diesel generator is frequently used [11]. Several studies have been carried out around the globe to investigate wind energy potential or wind and solar energy potentials for electricity generation. These include but not limited to [12 – 16]. This present study focused on three distinct locations in Kebbi State.

1.1 Resource Assessment

Solar radiation assessment forms the foundation for any photovoltaic system deployment. Various methodological approaches have been developed to estimate solar radiation at locations where ground-based measurements are limited. The Angstrom-Prescott model, originally developed. Subsequently it was modified by Prescott, remains one of the most widely applied empirical models for estimating global solar radiation from sunshine duration records. The model is expressed as:

$$H = H_0 \left(a + b\frac{n}{N}\right) \quad (1)$$

where H is the monthly average daily global solar radiation, H_0 is the extraterrestrial solar radiation, n is the actual sunshine hours, N is the maximum possible sunshine hours, and a and b are empirical coefficients [5].

For locations where sunshine duration data are unavailable, temperature-based models provide alternative estimation approaches. The Hargreaves-Samani model utilizes daily maximum and minimum temperatures: $H = H_0 \text{ x } a \text{ x} \sqrt{T_{Max} \text{-} T_{Min}}$ (2)

where T_{Max} and T_{Min} are maximum and minimum temperatures, a is an empirical coefficient typically ranging from 0.16 to 0.18 for inland locations. More sophisticated approaches employ satellite-derived datasets, which have become increasingly accessible and reliable. The Photovoltaic Geographical Information System (PVGIS) provides solar radiation data with reasonable accuracy for most African locations.

For northern Nigeria specifically, [5] conducted comprehensive assessment using both ground-based and satellite data, confirming that solar radiation remains consistently high across all regions, with values averaging above 21 MJ/m²/day. The study employed statistical modelling approaches with predictive deviations within ±0.3 MJ/m²/day, demonstrating the reliability of modern estimation techniques. The clearness index, a dimensionless measure of atmospheric transmittance, is frequently used to characterize solar resource availability:

$$K_t = \frac{H}{H_0} \quad (3)$$

This index provides insights into cloud cover and atmospheric conditions affecting solar resource availability [11].

The discovery of significant solar potential is consistent with prior regional studies for instance [17], confirming that Kebbi State is a good location for solar PV implementation. GHI values consistently exceeding 5.5 kWh/m²/day are world-class, resulting in significant energy yield.

1.2. Hybrid System Optimization

The optimization results significantly support a decentralized, photovoltaic-based mini-grid with battery storage. The modest differences in system size and cost across the three districts are directly related to the resource data: Yauri, having the lowest solar resource, requires a slightly larger (and more expensive) system to satisfy the same load demand.

The LCOE of approximately $0.19 per kWh is a compelling value proposition. It is comparable to, or less expensive than, the national grid tariff (when accounting for the cost and dependability of backup generators), and far less expensive than diesel. This economic advantage, together with the environmental and social benefits, presents a compelling case for the use of such systems by government agencies (such as the Rural Electrification Agency - REA) and private enterprises.

2. METHODOLOGY

2.1. Description of the Study Area

This study focuses on three Local Government Areas (LGAs) in Kebbi State, most of which are the headquarters for senatorial district.

Table 1: Geographical locations of the study area

S/No	Location	Latitude (°N)	Longitude (°E)	Altitude (m)
1	Argungu	12.7333	4.5333	156
2	Jega	12.2167	4.3667	173
3	Yauri	10.8333	4.7500	125

All three locations are in the tropical continental climate zone, which has two different seasons: dry (November-March) and wet (April-October).

2.2. Data Collection

The key data for this study is the meteorological time-series data. Because there were no high-quality, long-term ground-based measurements available at the desired specific sites, satellite data from the NASA Prediction of Worldwide Energy Resources (POWER) project was used. This dataset has been extensively tested and accepted for renewable energy feasibility assessments in data-scarce regions [18]. The following data were gathered for each site for a period of 22 years (January 2000 - December 2022):

- Solar Radiation: Monthly average Global Horizontal Irradiance (GHI) in kWh/m²/day.
- Monthly average wind speed at 10 m and 50 m heights in meters per second.
- Monthly average air temperature at 2 m in degrees Celsius.
- Clearness Index: The monthly average dimensionless index.

2.3 Load Estimate

A load profile for each typical off-grid rural community of roughly 200 households was developed using field surveys and literature. The neighborhood consists of residential dwellings, some schools, a community health center, a few small stores, a water pumping system, and central mosque. The demand for Jega is approximately 8 MW, 10 MW for Argungu and 3.9 MW for Yauri.

2.4 System Components and Specifications

The components listed below were considered for the hybrid system design of HOMER.

- Generic flat-plate PV panels cost \$800/kW to install, \$750/kW to replace, and \$100/year for operation and maintenance. The derating factor was set to be 80%, and the lifetime was 25 years.
- A generic 3 kW tiny wind turbine was studied. The capital cost per unit was \$6,000, with a replacement cost of \$5,500 and an annual operating and maintenance cost of \$100. The hub height was set at 25m, and the life expectancy was 20 years.
- A standard 1 kWh lead-acid battery was used for storage. The capital cost was \$300/kWh, with a replacement cost of \$300 and an operating and maintenance cost of \$10 per year. The round-trip efficiency was 85%, and the lifetime was five years making it require replacement 4 time for the life time of the system.
- Converter: A system that manages AC/DC power flows. The capital cost was \$300 per kW, with \$300 replacement cost and a \$0 annual operating and maintenance cost, with an efficiency of 95%, and the life span of 15 years. The salvage value of a converter replaced after 15 years is the undepreciated portion of its original cost which was determined by the chosen depreciation method. In straight line depreciation terms, it is the fraction of life remaining at the replacement time.
- Salvage value = Replacement cost × (Remaining life/Component lifetime)
  Salvage value = \$300 × (10yrs/25yrs)
- To address system constraints, a Load Following (LF) dispatch approach was adopted. To maintain excellent reliability, the annual capacity shortfall was set at no more than 1%.

2.5 Optimization and Modelling Tool

HOMER Pro software (version 3.14) was used for techno-economic optimization. HOMER mimics the operation of a system by calculating the energy balance for each of the 8,760 hours in a year. It then calculates the ideal system configuration using the total Net Present Cost (NPC) and Levelized Cost of Energy (LCOE). The software optimizes by altering component sizes and ranking the possible combinations using NPC.

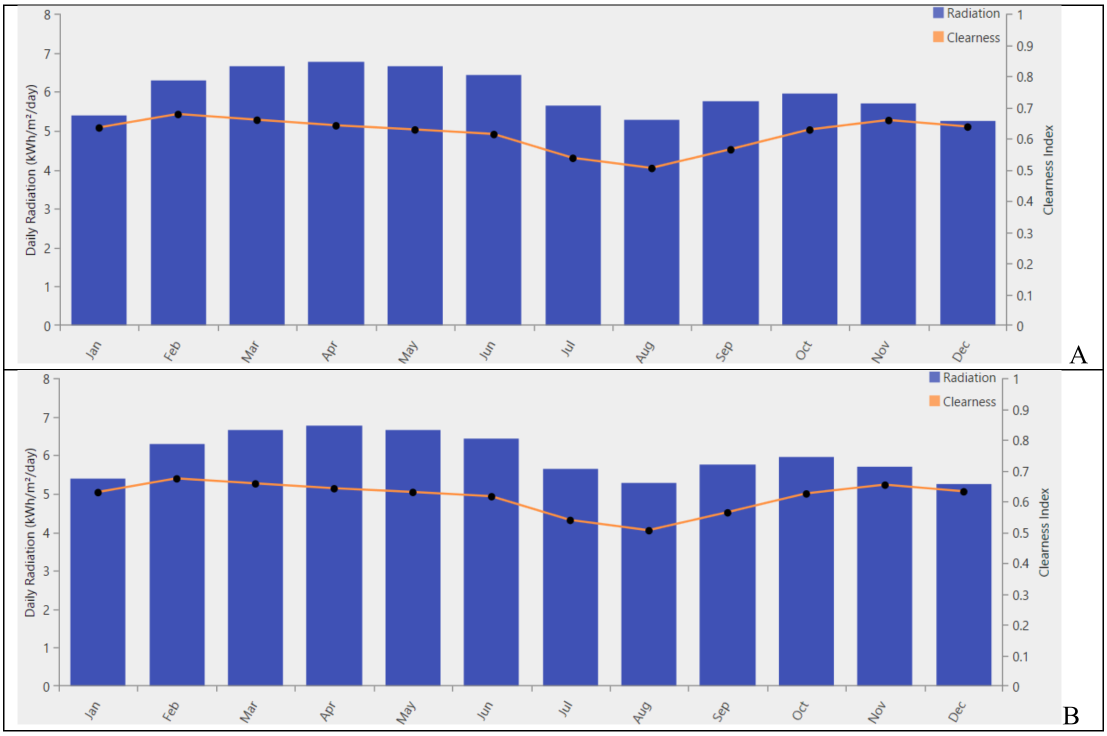
3. RESULTS AND DISCUSSION

3.1 Solar Resource Potentials

The review of the 22-year NASA data revealed that for all the three locations the average solar resources are very high, which is typical of the Sahel region. The annual average solar radiation and clearness index are shown in Table 2.

Table 2: Solar resource potential in the study areas

Location	Senate District Average GHI (kWh/m²/day)	Average Annual Clearness Index
Kebbi North (Argungu)	5.88	0.58
Kebbi Central (Jega)	5.88	0.52
Kebbi South (Yauri)	5.68	0.56



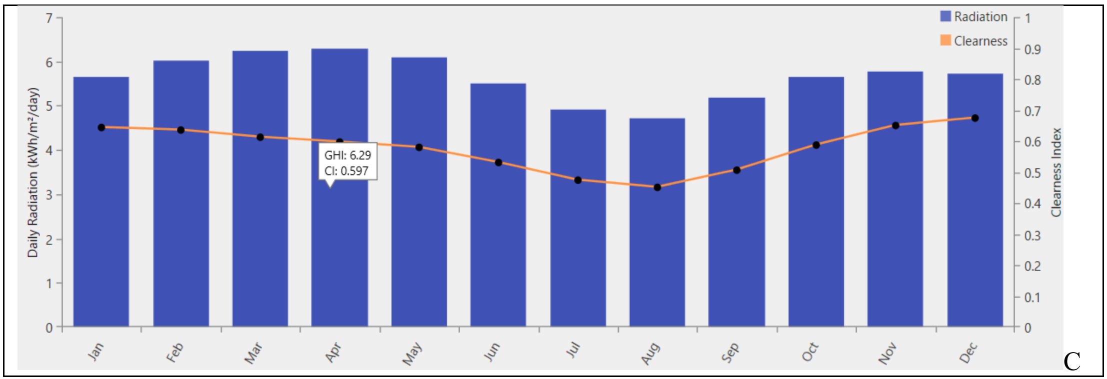


Figure 1: Annual average of solar radiation and clearness index for (A) Argungu (B) Jega and (C) Yauri

- Solar Radiation is the amount of sunlight energy that reaches your site and can be converted in to electricity by a solar PV system.
- The clearness index measures how much solar radiation makes it through the atmosphere to the earth surface. It is defined as: $K_T = \frac{H_{avg}}{H_0}$ (4)

where
H_{Avg} = Monthly average daily radiation on horizontal surface at ground level.
H_0 = Radiation at the top of the atmosphere.
K_T = is the dimensionless number between 0-1.
$K_T \approx 0$: Very cloudy and most sunlight blocked.
$K_T \approx 1$: Very clear atmosphere and most sunlight reaches the ground.

Figure 1A shows the variation of the annual average solar radiation and clearness index for Argungu. A critical examination of the figure with figure 1B revealed that both Jega and Argungu have close vicinity in Kebbi State, the solar data reported for Jega has similar pattern of variation similarly typical of that of Argungu. Argungu has exceptional solar resources, as seen in the table, with an average yearly radiation of 5.88 kWh/m²/day. The pre-monsoon dry season is when solar energy peaks the most, reaching a maximum of 6.8 kWh/m²/day in April—perfect for high-yield power generation. High levels of air transparency are confirmed by the clearness index, which peaks in February at 0.70. However, there is a notable seasonal reduction during the West African monsoon (July to September), when cloud cover causes radiation to fall to its yearly low of 5.3 kWh/m²/day in August. The resource is nevertheless reliable enough to support solar hybrid investments in spite of this rainy season fluctuation.

Figure 1B show a very clear seasonal pattern in Jega solar resource statistics with an excellent solar potential as confirmed by the high yearly average radiation of 5.88 kW/m²/day. During the dry season, radiation peaks, peaking at 6.8 kW/m²/day in April. A gauge of atmospheric transparency, the clearness index, falls between 0.49 and 0.70. The data amply demonstrates the effects of the rainy season (July–September), when increased cloud cover causes radiation to drop to its lowest point (5.3 kW/m²/day in August) coupled with the lowest clearness index. The radiation levels are still suitable for producing electricity in spite of this monsoon-related decline.

Figure 1C exhibit that Yauri's solar data has a robust resource profile that is appropriate for the development of renewable energy, despite some variation. The area has peak insolation during the pre-monsoon months, with an average yearly radiation of 5.68 kWh/m²/day. Throughout the dry season (October to April), the clearness index maintains modest values, peaking at 0.66 in December. The greatest radiation levels are recorded in April at 6.3 kWh/m²/day. During the peak rainy season (July–September), there is a marked seasonal trough. In August, radiation reaches its yearly minimum of 4.8 kWh/m²/day, which corresponds with the lowest clearness index of 0.50. This suggests that there will be a lot of cloud cover throughout the monsoon. The resource is nevertheless profitable even though Yauri's radiation during the dry season is marginally lower than that of places further north. In order to provide year-round energy reliability, these conditions strongly promote hybrid system architectures, in which battery storage makes up for the monsoon cloud cover.

The results reveal little difference throughout the state, with Argungu having the most promising and good prospect of electricity generation.

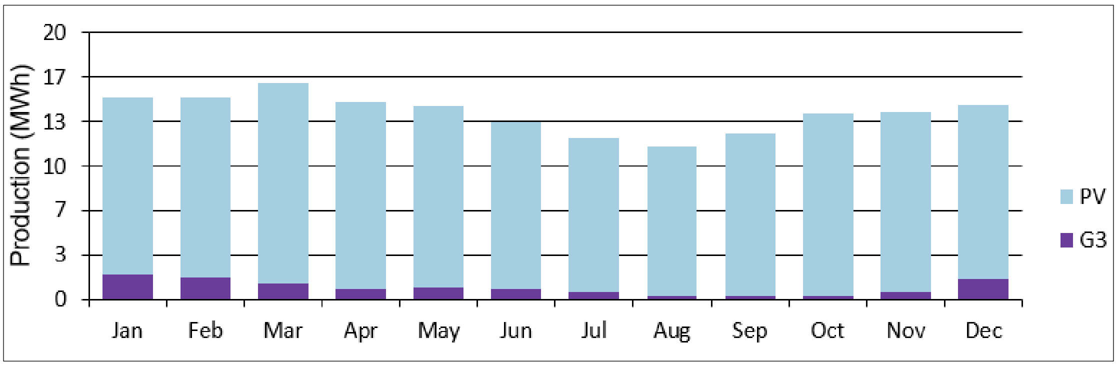


Figure 2: Electric consumption

Figure 2 shows that solar radiation is peak during the dry season (March-May), decreases somewhat during the rainy season (August), and remains consistently high (> 4.5 kWh/m²/day) throughout the year, making solar PV a highly reliable source.

3.2. Wind Resource Potential

The wind resource assessment showed moderate-to-low wind speeds throughout the state, with a minor increase from south to north. Table 3 summarizes the annual average wind speeds at normal heights (10 m – 50 m). The wind resource, however, paints a different picture. The mean speeds are less than the 4.0 m/s barrier, which is commonly considered as the minimum for cost-effective small-scale wind generating. While the seasonal complementary with solar is intriguing, the total energy captured by a wind turbine would be insufficient to justify its capital cost. This means that, given present technology and economics, standalone wind or large-scale wind-solar hybrid systems are not yet feasible in this area. This conclusion is essential for avoiding mistaken wind energy investments in Kebbi State [19].

Wind resource assessment requires statistical characterization of wind speed distributions, as wind power density varies with the cube of wind speed. The Weibull probability distribution function is universally accepted as the standard model for wind speed characterization [20].

For northern Nigeria [5] identified significant spatial variability in wind resources, with Plateau, Nasarawa, Borno, Yobe, Katsina, and Kebbi showing the highest potentials, particularly during the dry season when wind speeds peak. The seasonal complementarity between wind and solar resources in this region with wind peaking during the dry season when solar radiation remains high but cloud cover is minimal creates favorable conditions for hybrid system deployment.

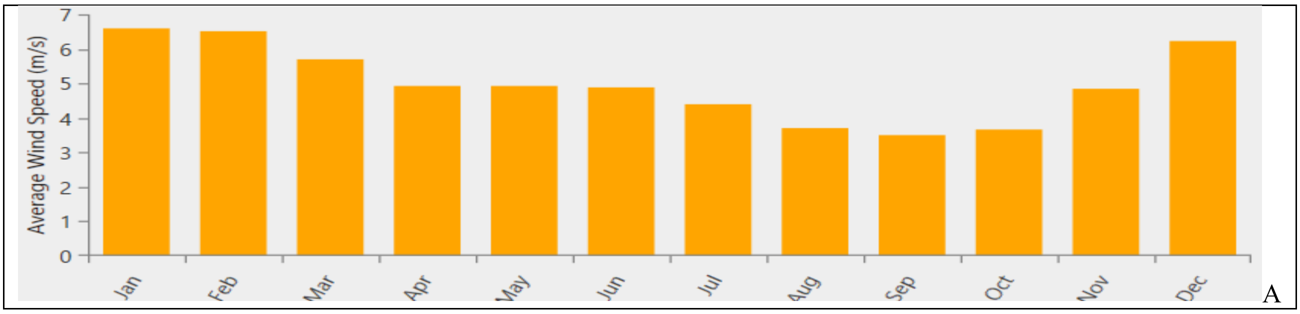
Wind resource data was presented at standard meteorological height (10 m is standard for surface observation and 50 m is typical for small wind turbine hub). HOMER automatically extrapolates between these two inputs heights to estimate the wind turbine at the specific hub height which is 25 m. Using the logarithmic law

$$v_{25} = v_{10} \cdot \frac{ln(25/z_0)}{ln(10/z_0)} \qquad (5)$$

where Z_0 is the surface roughness. The interpolated wind speed at 25 m using the logarithmic interpolation between 10 m - 50 m data is:

Table 3: Summary of Wind Resource Potential in the Study Areas

Selected Location	Wind Speed (m/s) 10m	Wind Speed (m/s) 25m	Wind Speed (m/s) 50m
Argungu	3.14	3.66	4.00
Jega	3.16	3.64	4.01
Yauri	2.83	3.27	3.61



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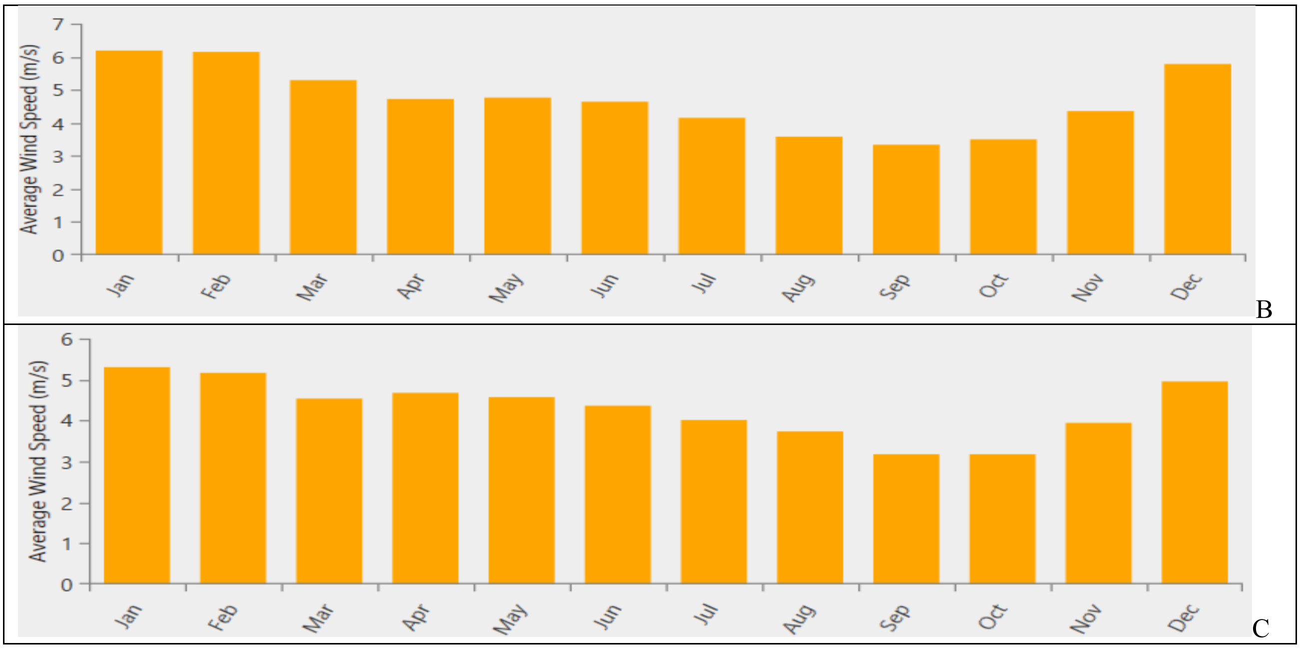

Figure 3: Annual average wind speed for Argungu, Jega and Yauri

Figure 3A demonstrated Argungu's average wind speed data shows a clear seasonal pattern with strong Harmattan winds and a notable monsoon slowdown. Small-scale wind turbines may operate at the average yearly wind speed of about 3.14 m/s. During the dry season, the northeast Harmattan winds cause wind speeds to spike sharply, peaking at 6.6 m/s in January. Because it falls during the time of maximum solar radiation, this powerful winter wind resource is a wonderful complement to solar energy. On the other hand, the peak rainy season is when wind speeds are lowest, reaching a minimum of 3.5 m/s in September. Argungu is a perfect choice for a hybrid wind-solar system because of its seasonal complementarity, where high winds occur when solar is abundant and weak winds align with the monsoon cloud cover. This allows the resources to automatically balance each other throughout the year. Figure 3B clearly shows Jega's average wind speed data shows a useful seasonal trend that is perfect for hybrid energy systems. For low-wind-speed turbine technology, the yearly mean wind speed of about 3.16 m/s is adequate. During the dry Harmattan season, wind speeds reach a maximum of 6.2 m/s in January. Complementary energy generation is made possible by this powerful winter wind resource, which coincides with the peak sun radiation time. During the wet season, wind speeds drastically decrease, reaching their yearly minimum of 3.3 m/s in September. Strong winds increase generation during periods of plentiful solar radiation, while cloud cover reduces solar irradiance during the low-wind monsoon period. This seasonal profile produces a complementarity of natural resources. This trend demonstrates to Jega that a hybrid wind-solar system with sufficient battery storage will maximize the gathering of renewable energy and guarantee a consistent power supply throughout the year. S can easily be observed figure 3C annual average wind speed for Yauri in comparison to northern Kebbi locations, the average wind speed data for Yauri shows a much calmer wind regime, with an annual mean wind speed of about 2.83 m/s, which is still not feasible for low-speed turbine technologies but with lower energy yield expectations. Wind speeds peak during the Harmattan season, peaking at 5.3 m/s in January, and then gradually decrease throughout the dry season, with a dramatic minimum during the late rainy season, when they drop to just 2.2 m/s in September and October, the lowest recorded in the region. This profile shows that although Yauri follows the same seasonal complementarity pattern as other locations, the absolute wind resource is weaker. This implies a higher dependence on solar photovoltaics and battery storage for hybrid system design, with wind supplying supplemental rather than primary generating capacity during the coldest winter months.

Wind speeds at 50 m are marginally higher, but they are still below the cut-in speed for most commercial small wind turbines (3-4 m/s). Figure 2 depicts a seasonal trend in which the highest winds occur during the harmattan period (December-February), while the rainy season has the calmest winds. This pattern is inversely associated with solar radiation, indicating the possibility of seasonal complementarity.

3.3 Optimization Results and System Configuration

The HOMER optimization software simulated thousands of different system setups. The results were astonishingly consistent across all three locations: a PV-Battery hybrid system was the most cost-effective and dependable. The addition of a wind turbine was never optimized in the top-ranked configurations due to the low wind speeds, which resulted in a relatively poor capacity factor for the turbine, making it financially unattractive when compared to adding more PV or battery capacity.

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Table 4 below shows the appropriate system configuration for each location based on the community load profile.

Table 4: Optimal PV-Battery Hybrid System Configuration and Costs

Location	PV (kW)	Battery (kWh)	Converter (kW)	Initial Capital ($)	NPC ($)	LCOE ($/kWh).
Argungu	24.5	95	8.2	38,250	81,234	0.186
Jega	23.5	95	7.5	38,000	81,250	0.186
Yauri	26.0	105	8.5	40,550	87,210	0.199

The LCOE for the suggested systems ranges from $0.186 to $0.199 per kWh. This is much cheaper than the predicted LCOE of a diesel-only generator for the same load, which was calculated to be more than $0.45/kWh, taking into account fuel transport and maintenance expenses in a remote site. The standard levelized cost of energy equation is given by:

$$LCOE = \frac{NPC}{\sum_{t=1}^{n} E_t \times (1+r)^{-t}} \qquad (6)$$

Where

NPC = Net Present Cost of the system

E_t = Energy generated in a year

r = discount rate

n = project life time

For the PV-Battery hybrid system without diesel backup (as implies in table 3), the LCOE comparison with a diesel-only system is :

$$LCOE_{\text{hybrid}} = \frac{NPC + battery + converter}{\sum_{t=1}^{n} (E)_{PV,t}} \qquad (7)$$

$$LCOE_{\text{hybrid}} = 0.186 - 0.199\$/kWh$$

$LCOE_{\text{hybrid}} > 0.45\$/kWh$ Thus, the hybrid system is economically feasible when:

$LCOE_{\text{hybrid}} < NPC_{diesel}$ *and* $0.186 < 0.45$ [21].

4.0 CONCLUSIONS AND RECOMMENDATIONS

This study effectively evaluated the wind and solar resource potentials and conducted an optimization analysis for a hybrid energy system in three senatorial districts of Kebbi State, Nigeria. The main conclusions are:

1. Argungu, Jega and Yauri of Kebbi State has exceptional solar energy potential, with yearly average GHI values above 5.5 kWh/m²/day, making it ideal for solar PV power generation.
2. The state's wind energy potential is limited, with average speeds of less than 4 m/s at 50 m, making it commercially unviable for power generation with present equipment.
3. A freestanding solar PV-battery hybrid system is the most cost-effective option for off-grid rural electrification in the region, according to techno-economic optimization.
4. The optimized system's Levelized Cost of Energy (approx. $0.19/kWh) is more cost-effective than fossil-fuel alternatives, providing a sustainable and inexpensive energy solution.

Based on the results of this study, the following recommendations are made:

1. Kebbi State Government and Rural Electrification Agency (REA) should adopt the PV-Battery hybrid mini-grid model as a standard design to electrify rural communities. The findings of this study should be used for preliminary planning and budgeting.
2. Project Developers should prioritize implementing solar PV systems with suitable battery storage. Avoid incorporating wind turbines in system designs for this region unless site-specific research finds a wind microclimate significantly superior to the regional average.
3. For future research, conduct extensive ground-based wind measuring campaigns at specified sites to eliminate wind potential. Further research should look into the social and economic implications of deploying such mini-grids, as well as effective ways for integrating productive energy use (for example, agricultural processing) to improve the projects' financial sustainability.
4. Policymakers may create an enabling environment for mini-grids by expediting permitting processes and offering incentives like tax rebates on imported solar components to lower initial capital costs.

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