

# Multi-temporal assessment of wind, solar, and hydropower resources for off-grid microgrid

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## ABSTRACT

For a proposed multi-source all-renewable microgrid in Nigeria's Middle-belt region, this paper presents a multi-temporal approach to the investigation of the uncertainty in the potential of renewable energy resources. The wind, solar, and hydropower resources for a proposed multi-source all-renewable off-grid community microgrid are considered using an array of probabilistic techniques. The peculiar variances in the location's climate throughout the year make the more common method of annual models of renewable resources unsuitable for power system planning. Consequently, a more granular model of its renewable resources over time is needed. Therefore, for the chosen location, for each renewable resource, a composite multitemporal maximum-likelihood estimation-based (MLE) probabilistic model for characterization is developed. A total of 39 probabilistic models are developed. Up to 40% improvement in the accuracy of the statistical measures for renewable resource uncertainty was observed. Multi-temporal approach provides more accurate information for power system planning over time than the conventional approach of single aggregate models, especially for hydropower, which is strongly affected by the relatively sporadic occurrence of rainfall. The study shows that solar energy is promising, hydropower potential is seasonal and complementary, and wind potential is low at the location considered in this study.

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## 1. INTRODUCTION

The importance of renewable energy in the evolved societies of the modern era is one of the most actively-discussed topics in the conversation on the sustainability of technology-driven civilizations globally [1]. Reasons for the emergence and increasing endorsement of renewable energy technologies include concerns about global warming and the attendant climate change, health hazards associated with pollution from the by-products of fossil-fuel use, as well as the finiteness and potential exhaustion of fossil fuel reserves [2]–[4]. For these among other reasons, renewable energy has gained prominence in the global discourse. Africa is the second most-populous continent on the globe [5] and is on track to become the continent with the largest population [6]. Nigeria is the African nation with the highest population [7]. Nigeria also possesses abundant renewable and non-renewable energy resources. It is a tropical nation in which many rivers flow, including the Niger River, the third-longest river in Africa (reflecting hydropower potential) [8]. The nation also has over 900,000 square kilometers of land and a varied climatic landscape, including dry, well-insulated, and arid regions (reflecting solar photovoltaic and solar thermal potential) and

biomes with different vegetation systems (reflecting biomass potential) [9]. It is a coastal nation (reflecting wind energy potential) [10]. In addition, Nigeria is a country with natural gas, oil, and coal reserves [11]. Even with this abundance of natural endowments in terms of energy resources, less than two-thirds of the country's population has electricity access, and those who do have it frequently suffer poor quality of service, which negatively impacts the quality of life in the country [12]–[16].

The power generation in Nigeria is centralized, with a few large power plants. Also, large-scale hydropower is the only form of renewable energy known to be harnessed on a multi-megawatt scale in Nigeria at the time of this research. Microgrids and distributed generation are concepts that have not significantly gained ground in Nigeria. Nevertheless, there have been successful implementations of standalone microgrids [17], [18]. A major factor in the receptiveness to microgrid implementation is the combination of economic, socio-political, and technical difficulties associated with implementing grid extensions [19]. Thus, many communities are left with no grid access and it is very common for Nigerian homes and businesses to own, kilowatt-scale diesel-, gas-, or petrol-fueled generating sets, commonly and informally referred to in Nigeria as “I-pass-my-neighbor” [20]–[22]. In discussing energy matters on a global scale, the need for renewable energy to replace and minimize fossil-fuel generation is a common theme. However, in many African communities, fossil-fuel generation, even when un-curtailed, is insufficient and inadequate to supply the needs of the economies [23], [24]. In other words, developed nations participating in the renewable energy transition have usually already attained energy sufficiency for their economies in the present day, but want to replace fossil fuels with renewable energy for their economies, while developing nations, such as Nigeria, are yet to attain energy sufficiency in the first place. This has had several implications for the prospects and importance of renewable energy in Nigeria.

The Nigerian transmission network is prone to collapse due to instability and is radial [25]. Furthermore, a significant proportion of the country's population is not served by the transmission network. The extension of this transmission network, which already suffers instability issues, is a complicated matter technically, economically, and socially. This is because not only could the grid be further destabilized by major extensions without very detailed planning and analysis, but the economic prospects are also daunting. There also exist terrains across which it is difficult to extend the transmission network. Furthermore, in many of Nigeria's rural/remote communities where grid connections can be found, such connections are negatively impacted by a relative (and sometimes absolute) lack of maintenance when compared to grid sections in urban centers [26]. Thus, for many rural or neo-urban communities in Nigeria, a localized standalone power generation system (such as a microgrid) presents the most viable, sustainable, satisfactory, and feasible solution to the lack of or the inadequacy of electrical energy access.

It is desirable that for new power generation systems, renewable options are prioritized. This is per the seventh United Nations' Sustainable Development Goal which emphasizes the provision of access to energy that is affordable, sustainable, and not harmful to the environment or the people in it [27]. For localized power generation, non-polluting renewable energy sources (which excludes biomass) present significantly-less health hazards than fossil-fuel options [2]. However, in an all-renewable microgrid system that stands alone, the intermittent of renewable resources such as wind, solar, and small-hydropower energy presents levels of uncertainty that could critically impact the functioning of such systems. Thus, it is important to assess these renewable energy resources before significant financial investments are made.

In the choice of location for this study, it was considered that the northernmost regions of Nigeria are associated with relative dryness and aridity, with weather and climate being dominated by the influence of the Sahara Desert, with solar power being applicable, and with a major challenge to this being dust [28]. Conversely, the southernmost regions of Nigeria are associated with marine and coastal biomes, with solar power also being applicable, as well as small-hydropower and wind due to the abundance of water [29], [30]. However, in Nigeria's middle belt region, renewable energy resources are subject to climatic influences from both the north and the south and are thus worthy of further study.

The key concept in this study is the idea that for the planning of renewable energy installations that are to operate mostly or completely without support from the larger grid, the aggregated statistical distributions using entire time-series datasets (such as the Weibull distribution for wind), can provide an expectation of the general performance of local energy resources. However, these applications of statistical techniques on aggregated annual datasets are not able to provide information on the performance of the energy resources across months and seasons of the year. Thus, these distributions can be used across separate time divisions and resolutions to develop a multi-temporal model that gives more information about the seasonal and monthly variations in renewable energy resources.

In this work, the wind energy potential at the chosen location is investigated across different temporal divisions using the maximum-likelihood estimation (MLE) methods in combination with the Weibull distribution in terms of shape and scale parameters. The solar energy potential is investigated using the Lognormal distribution with an MLE estimation, while the micro-hydro power of the chosen river, the

Oshin River, is investigated using the Gumbel/extreme-value (EV) distribution with the MLE estimation method. While several software applications, such as the hybrid optimization of multiple energy resources (HOMER Pro) and RETScreen applications, are commonly and successfully used for microgrid planning and assessment, these software applications are designed to work with entirely contiguous datasets to give unified information, with limited control over the temporal resolution [31]. Additionally, the assessments that are most frequently aided by these software applications are designed to consider the detailed load data, usually at an hourly resolution. Thus, such study methodologies are not entirely able to provide the multi-temporal, multi-energetic perspective desired in this study, which is attempted for the first time in this study. For this reason, probabilistic methodologies for renewable resource assessment have been used by studies [31]–[44]. However, while most studies have focused on comparing locations for specific renewable technologies, this study compares multiple renewable resources at a single location using a different probabilistic approach for each. Thus, it can be said that this work is an aggregate of separate studies on each of the three different renewable resources considered. In addition to providing results on the renewable energy sources considered at the chosen location, whose importance has been established earlier, this work also presents a repeatable methodology for similar use cases in other locations in Nigeria, both of which are being attempted for the first time in this study.

## 2. METHOD

### 2.1. Site and data description

The three different renewable energy sources of wind, solar, and micro-hydropower using the Oshin River are investigated. Arandun is located in Nigeria's savanna climatic region. It experiences two annual seasons, the wet/rainy season which peaks around July, and the dry/harmattan season which peaks around January. Total yearly precipitation between 700 and 2,600 mm is usually obtained, feeding the streams and rivulets in the community. The wind and solar data over Arandun are provided for analysis by NASA [45], with the coordinates of the town being 8° 4' 59" N and 4° 57' 0" E. The community is an urbanizing town, with this process being helped by the availability of land. Thus, the communities in this region of Kwara State, Nigeria, including this one, have been growing both in physical size and in terms of population. The solar and wind data are provided for the location from January 2001 to December 2021 and used in this study. This corresponds to a rich dataset with each of those variables having over 184,000 data points. Specifically, the wind speed at a height of 50m, the ambient temperature (on the Celsius scale), and the Global Horizontal Irradiance (in Wh/m<sup>2</sup>), as well as the wind direction, were harvested from the database. A map of Arandun is provided by Google in Figure 1.

On the other hand, after a physical survey of the community, the Oshin River, a fourth-order stream flowing with an upper catchment of 70 km [46], was selected for the micro-hydro, as it flows through the community, well away from the city Centre. The data for the hydropower modelling was gathered by repeated gauging of the Oshin River in Arandun. The flow velocity, width, and depth of the river at different points, measured during the high and low points of its annual cycle, were probed and these data were used to develop a monthly profile for the streamflow (in Liters/second) that was then used in this study. Measurements obtained in this study are an underestimation of the river's true potential because of some obstacles (vegetation) along the course of the river, which slows it down significantly in the dry/harmattan season. Consequently, the gauging was done at different points along the river's course and then averaged to account for this factor as much as possible.

The velocity-area method as elaborated upon in [47] was used to compute the streamflow. In this method, the velocity of the river flow was measured by timing floating objects across a fixed distance. The cross-sectional area of the river was estimated by measuring the depth and width of the river at different points. The river depth and head were also measured over a section of its course using the hose-level method recommended in [47] (also during the dry season, restricted to the shallower parts both for safety and topographical measurement accuracy). Figure 2 shows the method used for gauging the head of the Oshin River in Arandun as well as a picture of the researcher gauging the pressure head of the river in the dry season in February. The streamflow is finally computed as the product of the velocity and the cross-sectional area. The equation for computing the streamflow is given in (1) and (2).

$$F_s = A_c \times V_s \quad (1)$$

where:

$$A_c = d_s \times w_s \quad (2)$$

In (1) and (2),  $F_s$  is the streamflow of the river in Liters/second,  $A_c$  is the cross-sectional area of the river in  $m^2$ ,  $V_s$  is the stream velocity in m/s,  $d_s$  are the average depth of the river at the point at which the cross-sectional area is being measured, while  $w_s$  is the width of the river at the same point, all distance units being in meters. In lieu of presenting the entire dataset used, the descriptive statistics for the data are provided in Table 1.

Table 1. Preliminary descriptive statistics on the renewable resource data in the study

Data	Wind speed (m/s)	Temperature (°C)	Insolation (Wh/m <sup>2</sup> )	Stream flow (L/s)
Minimum	0.02	10.81	0.00	187.71
Maximum	10.33	40.29	1001.44	36463.83
Median	4.21	24.21	9.63	3155.54
Mean	4.06	24.97	208.51	6983.07
Standard deviation	1.68	3.65	279.55	8492.22
Skewness	-0.14	0.49	1.02	1.36
Kurtosis	2.34	3.20	2.58	3.88

## 2.2. Maximum-likelihood estimation

The maximum-likelihood estimation (MLE) technique was used to fit the renewable resource data for solar irradiance, wind energy, and streamflow to a set of probability distributions as described. While regression is used in straight-line or polynomial functions, MLE, while less simple, is more universal and used for fitting a set of data to any probability distribution function, while also allowing the degree of fit of the data and the function to be assessed in terms of confidence intervals. Linear regression is a special case of the MLE method in which the function to be fit is a straight line. MLE is a method of estimating the parameters of an assumed probability distribution, given some observed data. It is suitable for any type of differentiable probability distribution function, which makes it suitable for all the types of probability distributions used in this study (Weibull, Lognormal, and Gumbel). In the data-processing stage, all negative values (which are outliers in the first place) are replaced with floating-point numbers as close to zero as allowed by the research computer's floating-point standard.

The formulation for the maximum-likelihood estimation method is presented for this study. Given the parametric probability distribution  $f$  (such as a Weibull distribution), with parameters  $x$  in parameter space  $X$ , with data set  $y$  containing any number of values denoted by  $n$ , the likelihood function,  $L$ , is obtained by evaluating as in (3).

$$L(x) = f(y; x) \quad (3)$$

MLE involves finding values of the parameters of  $f$  (such as the Weibull model's shape and scale parameters) that maximize the likelihood  $L$ , over the parameter space  $X$ , as presented in (4). The MLE is then used to obtain the best fit for the Weibull, Lognormal, and Gumbel distributions.

$$\hat{x} = \arg \max L_n(x; y); x \in X \quad (4)$$

## 2.3. Probability distributions used in the work

### 2.3.1. Weibull distribution

For modelling wind speed distributions, the Weibull distribution is well-established as a preferred choice in the literature due to its repeatedly verified suitability [31], [48]–[55]. In addition to the comprehensive Weibull distribution, the wind speeds were separated by month and then modelled to their Weibull distributions, giving a total of 13 Weibull distributions. The MLE concept is applied to the Weibull distribution as presented in [49], [56]. The Weibull distribution itself is given in (5) from [56].

$$f(v) = \left(\frac{k}{c}\right) \left(\frac{v}{c}\right)^{k-1} \exp\left(-\left(\frac{v}{c}\right)^k\right) \quad (5)$$

$$F(v) = 1 - \exp\left(-\left(\frac{v}{c}\right)^k\right) \quad (6)$$

$$Q(v) = (-\log(1 - v))^{1/k} \quad (7)$$

The average value of the wind velocity,  $v_m$  and the standard deviation,  $v$  are defined in terms of the Weibull shape ( $k$ ) and scale ( $c$ ) parameters which are given as (8), (9).

$$v = c \Gamma\left(1 + \frac{1}{k}\right) \quad (8)$$

$$v = \sqrt{c^2 \Gamma\left(1 + \frac{2}{k}\right) - \left(\Gamma\left(1 + \frac{1}{k}\right)\right)^2} \quad (9)$$

Upon determination, the shape and scale parameters are used to estimate the most likely wind speed ( $V_{ml}$ ), as well as the maximum energy component in the wind ( $V_{em}$ ), as given by (10) and (11) [49]. These two values are important for estimating the specifications of the turbine that will be best for the site, especially with regard to the rated wind speed and the most commonly expected operating conditions.

$$V_{ml} = c \left(\frac{k-1}{k}\right)^{\frac{1}{k}} \quad (10)$$

$$V_{em} = c \left(\frac{k+2}{k}\right)^{\frac{1}{k}} \quad (11)$$

The given equations are used to quantify the expected energy density from the wind speed. Given that the wind power is proportional to the cube of the velocity, the equations (12) and (13) hold, where  $P_D$  is the wind power density (power per unit rotor area),  $\rho$  is the air density,  $V_m$  is the wind speed, and  $\Gamma()$  represents the Gamma function [49]:

$$P_D = \frac{1}{2} \rho v_m^3 \quad (12)$$

$$P_D = \frac{1}{2} \rho \Gamma\left(1 + \frac{3}{k}\right) c^3 \quad (13)$$

### 2.3.2. Lognormal distribution

The use of the lognormal distribution to characterize the solar energy distribution over time is well-established in literature [51], [57]–[63]. The formulation for its usage in this work is presented in [51]. The hourly data is used for this modelling after being separated by month. This ensures that the model includes the stochasticity due to the diurnal cycle of day and night. The lognormal probability distribution for this purpose is presented. Thus, between the comprehensive model and the monthly models, 13 separate lognormal models are fitted after the data is partitioned by month over the years. In (14),  $PDF_s$  is the density of the probability of the solar irradiance, and  $\mu_s$  and  $\sigma_s$  denote the mean deviation and standard deviation respectively.

$$PDF_s(G_s | \mu_s, \sigma_s) = \frac{1}{G_s \sigma_s \sqrt{2\pi}} \exp\left(-\frac{(\ln(G_s) - \mu_s)^2}{2\sigma_s^2}\right); G_s > 0 \quad (14)$$

The output of the photovoltaic system is then represented in (15), where  $P_{sr}$  represents the assumed rated power of the photovoltaic system (in this case, per unit area),  $G_s$  represents the solar irradiance in Arandun.  $G_{std}$  represents the solar irradiance when the insolation intensity is 1 sun (1,000 W/m<sup>2</sup>), and  $X_c$  represents a specific point of irradiance whose choice is important only if scheduling and load dispatch is being considered [64].

$$P_{pv,output} = \begin{cases} P_{sr} \left(\frac{G_s^2}{G_{std} \times X_c}\right) & \text{for } 0 < G_s \leq X_{cstd} \\ P_{sr} \left(\frac{G_s}{G_{std}}\right) & \text{for } G_s \geq X_c \end{cases} \quad (15)$$

### 2.3.3. Gumbel extreme-value (EV) distribution

The use of the Gumbel (EV) distribution to model the uncertainty of the streamflow of rivers is well-established in literature [65]–[70]. This is especially suitable because the EV distribution is favored in cases where the measurements in the study inherently contain information on the extreme behavior of the variable of interest [71]. In this study, most of the data used were taken around the time when the quantities

being measured (such as the depth, width, and speed) were at or near their maximums and minimums in a given time month. The EV distribution is presented in (16), where  $a$  and  $b$  are the position and scale parameters for the distribution respectively, and  $x$  is the variable (streamflow in liters/second) under consideration.

$$f(x|a, b) = b^{-1} \exp\left(\frac{x-a}{b}\right) \exp\left(-\exp\left(\frac{x-a}{b}\right)\right), -\infty < x < \infty, a > 0 \quad (16)$$

The streamflow data are divided according to the months and fit to the EV distribution giving 13 separate models.



Figure 1. Google map of Arandun

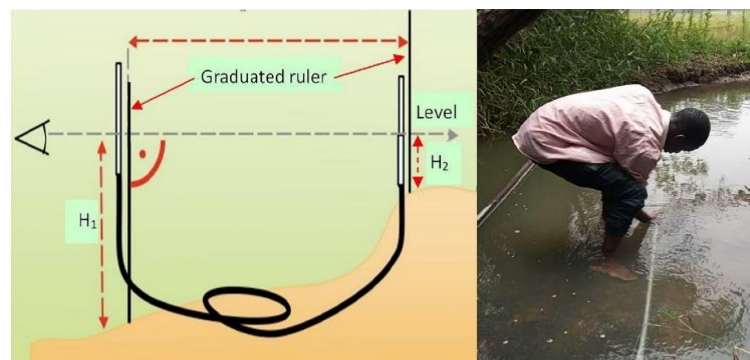


Figure 2. Stream-gauging of the Oshin River pressure head in Arandun

### 3. RESULTS AND DISCUSSION

The results of the probabilistic modelling are shown in Table 2 for the wind (Weibull), solar (Lognormal), and hydropower (Gumbel) resources respectively, while Figures 3, 4, and 5 show the fit of the aggregate (uni-temporal) distributions to the entire set of data used in the studies in the same order. From the results of the analysis, the mean wind speed in Arandun was found to be 4.06 m/s. The best wind speeds are obtained in April and August, while the lowest wind speeds are obtained in the last two months of the year. The power available in the wind varies accordingly, being governed by the cubic relationship with the wind speed. As Figure 6 shows, the peak months have just over 5 m/s<sup>2</sup> of average wind speed and 80 W/m<sup>2</sup> of

mechanical power (per unit rotor cross-sectional area) in the wind, while the least windy months have as low as 30 W/m<sup>2</sup> of mechanical power in the wind, as well as wind speeds of <4 m/s<sup>2</sup>. These speeds are generally lower than the cut-in speeds of most horizontal axis wind turbines (HAWTs), which are the most common and industry-standard turbines for harnessing renewable energy on medium or large scales. Thus, the wind potential in Arandun is quite low.

Table 2. Maximum-likelihood estimated parameters for probability distributions

Data	Weibull scale parameter (c)	Weibull shape parameter (k)	Lognormal mean deviation ( $\mu_s$ )	Lognormal standard deviation ( $\sigma_s$ )	Gumbel position parameter (a)	Gumbel scale parameter (b)
January	4.24	2.30	-15.20	20.86	261.71	25.32
February	4.52	2.51	-15.18	20.88	265.69	21.89
March	5.04	2.80	-15.14	20.91	1889.37	188.18
April	5.30	3.39	-13.56	20.73	5454.53	541.46
May	4.87	3.40	-13.54	20.72	8565.49	789.45
June	4.88	3.26	-13.57	20.69	29396.35	2972.20
July	5.23	3.61	-13.64	20.63	16546.25	1292.38
August	5.37	3.65	-13.69	20.58	17408.78	1543.09
September	4.19	2.64	-13.66	20.62	5167.38	530.44
October	3.67	2.47	-13.68	20.65	2051.71	240.34
November	3.44	2.33	-15.39	20.89	576.97	63.85
December	3.69	2.26	-15.23	20.85	276.81	21.78
Annual	4.56	2.62	-14.29	20.76	11702.64	10362.55

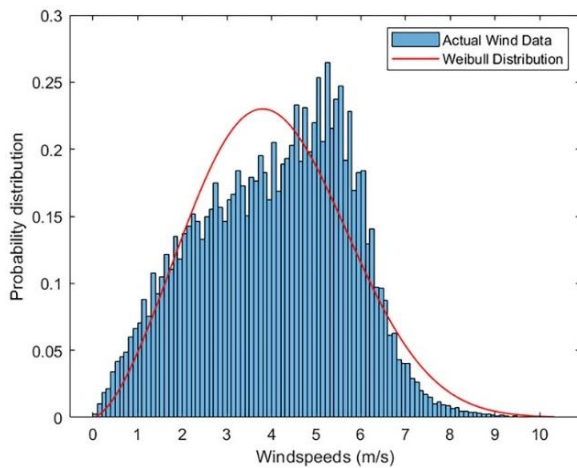


Figure 3. Empirical and estimated distribution for aggregated set of wind data

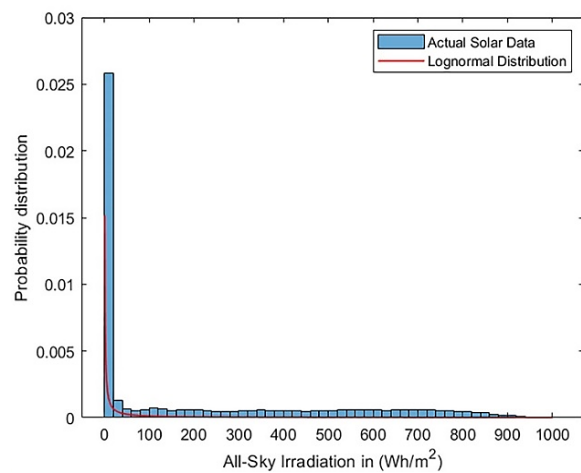


Figure 4. Empirical and estimated distribution for aggregated set of solar data

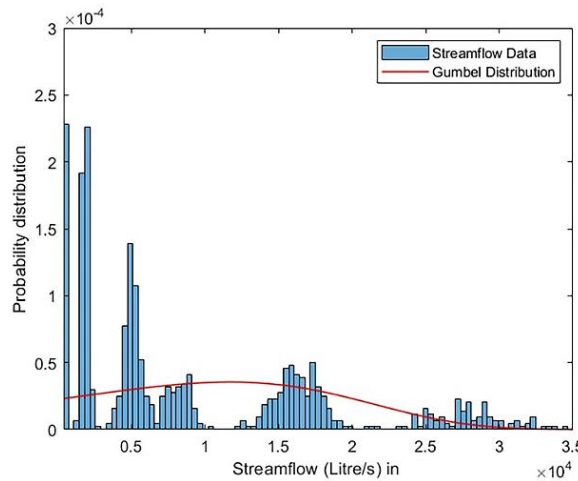


Figure 5. Empirical and estimated distribution for aggregated set of river data

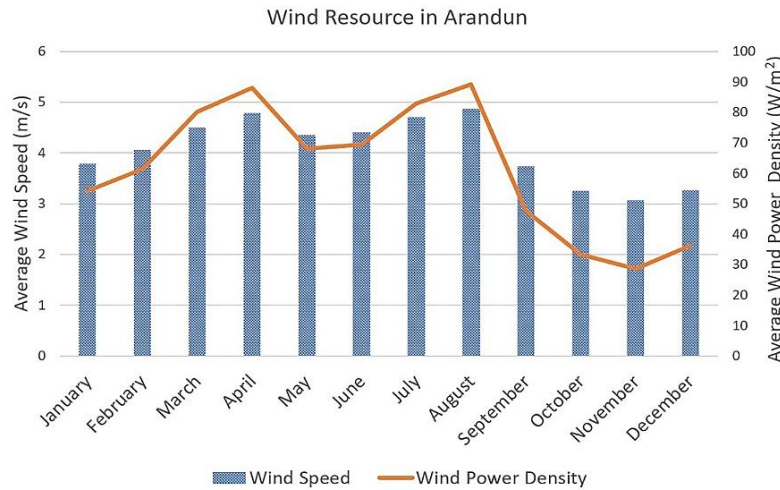


Figure 6. Average monthly flow rate (River Oshin) and precipitation for Arandun

The average daily solar irradiance (specifically GHI) in Arandun is charted in Figure 7. It is the lowest in August, at just over 4 kWh/m<sup>2</sup>/day. It is also highest in November, at just under 6 kWh/m<sup>2</sup>/day. This is explainable by the fact that the rainy season is accompanied by clouds that degrade the incidence of sunlight on the land in this period. With an efficiency of 20% for the solar panels, the mean insulation of 209 W/m<sup>2</sup> (accounting for night hours and variation) would result in about 40 electrical W/m<sup>2</sup> on average. Having a hectare (10,000 m<sup>2</sup>) of solar panels in this community would result in an average of 0.4 MW of electricity being generated on average, or 9.6 MWh of solar-based electricity a day, if an energy storage system (ESS) is provided to maximize the utilization of available energy by enabling dispatch of demand. Solar power would be less available in the rainy months. However, hydropower would be at its peak in these months if also operated at the location of the study.

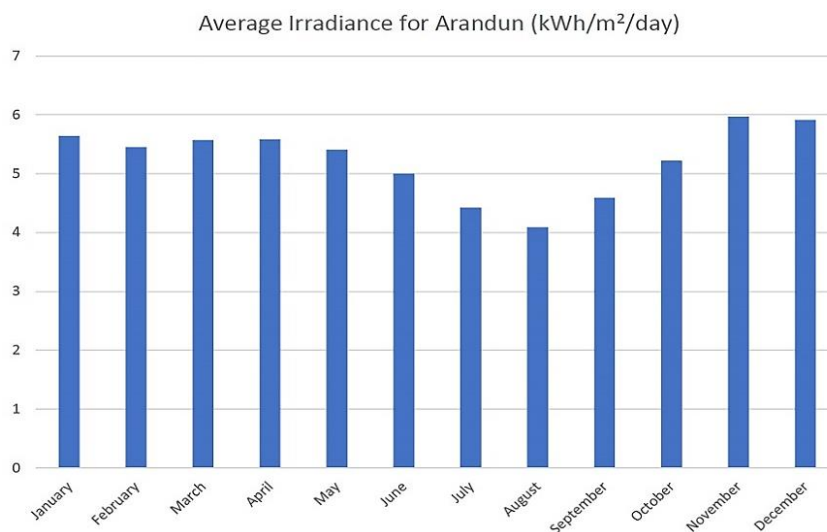


Figure 7. Monthly mean irradiance for Arandun (GHI)

### 3.1. Wind resource

The monthly and annual Weibull statistics for the wind speeds are presented in Table 2. It can be seen that the scale parameter (c) of the distribution using the annual statistics is 4.56. However, individual months show varying statistics. November has the lowest c value of 3.44, which corresponds to almost a 25% deviation from the annual statistics. On the other hand, the highest c value of 5.37 was found in August, which corresponds to a deviation of 18% from the annual statistic.



Thus, compared to the monthly Weibull statistics, the comprehensive annual statistic for the scale parameter of the wind distribution is not enough to provide enough information on the temporal performance of the wind resource across months and seasons. This is also the case when the shape parameter ( $k$ ) is considered. The shape parameter when the year is considered as a whole is 2.62. Yet, when the months are considered individually, the month of December shows as low as 2.26, which represents a 14% deviation from the annual statistic. On the other extreme, the month of August shows the highest shape parameter of 3.65, which represents a deviation of 40% from the annual statistic for the shape parameter of the wind's Weibull distribution.

These numbers show that for the characterization of the wind resource, the annual statistic may be sufficient for energy calculations on some level. However, multi-temporal models of the wind resource give more information on the uncertainty that can be expected over time. The loss of accuracy by using the aggregated annual model instead of multi-temporal (e.g. monthly) models can be expected to reflect in significant inaccuracies in power density calculations since the cubic relationship of wind power and wind speed means that average-related errors are exacerbated.

### 3.2. Solar resource

The monthly and annual log-normal statistics for solar irradiance (specifically the global horizontal irradiance, abbreviated as GHI) are presented in Table 2. It can be seen that the mean deviation ( $\mu_s$ ) of the log-normal distribution using the annual statistics is -14.29. However, individual months show varying statistics. November has the lowest  $\mu_s$  value of -15.39, which corresponds to a 7% deviation from the annual statistics. On the other hand, the highest  $\mu_s$  value of -13.54 was found in May, which corresponds to a deviation of 5% from the annual statistic. Also, the standard deviation ( $\sigma_s$ ) is considered. The  $\sigma_s$  value when the year is considered as a whole is 20.76. However, when the months are considered individually, the month of August shows as low as 20.58, which represents a 0.9% deviation from the annual statistic. On the other extreme, the month of March shows the highest shape parameter of 20.91, which represents a deviation of 0.7% from the annual statistic for  $\sigma_s$  of the lognormal distribution. These numbers show that for the characterization of the solar resource, the annual statistic is sufficient for the approximation of annual energy calculations. In addition, the low inaccuracies suggest that, for the solar irradiance, compared to the wind resource, there is not a critically important difference between using the annual statistics and using the monthly statistics, unlike that of the wind.

### 3.3. Hydropower resource

The Gumbel distribution is used in literature for modelling streamflow because it is an extreme-value phenomenon, which does not lend itself to a normal distribution. Furthermore, unlike solar and wind data with over 184,000 data points, the streamflow data has only 1,200 data points, which is a significantly smaller sample. Thus, the data available for this purpose is less robust than that for wind and solar resources. Due to these reasons, it is observed that the histogram for the observed streamflow data is more irregular and shows a relatively low fit with the theoretical (fitted) probability distribution curve compared to the other resources. However, the theoretical distribution and the observed data histogram in Figure 5 both show a right-tailed skew. This is also because the amount of precipitation varies more strongly across months than wind or solar radiation.

The position parameter ( $a$ ) of the Gumbel distribution based on the annual statistic was found to be 11702.64. The  $a$ -value was found to be strongly correlated to the amount of precipitation recorded in the month, which is a satisfactory physical interpretation of the location parameter. However, since the rainfall varies strongly across months, drier months such as January with an  $a$ -value of 261.71 are vastly different from the annual statistic. Thus, for January, the annual statistics would provide an estimate for the  $a$ -value which is inaccurate by up to 4,000%. Similarly, the annual scale parameter, the  $b$ -value, was found to be an ineffective predictor of the monthly scale parameters. The annual  $b$ -value was 10362.55, while the  $b$ -value for December was 21.78. This corresponds to the fact that there is frequently no or negligible rain in December in Arandun, with the precipitation being due to dew. This is because of the almost-constant probability of obtaining low precipitation in the Harmattan season, while during the rainy season, flash floods are a possibility, and the stream flow is less predictable. Thus, the annual statistics for  $a$  and  $b$  are skewed by the frequency of flash floods during the rainy season and do not adequately represent the month-to-month behavior of the river flow. Hence, the multi-temporal assessment approach is most strongly encouraged for the hydropower resource.

The streamflow is found to peak around the middle of the year as Figure 8 shows. In Figure 8, the average monthly streamflow and average monthly precipitation are presented, and it is seen visually that there is a strong correlation between both quantities, as can be expected, since the run-off from rain feeds the Oshin River. This means that the hydropower resource varies more strongly than other resources. A pressure head of 3 m over 1 km was obtained from the measurement. However, it should be noted that this is only a

short section of a long river. Using the basis of a low-head turbine to perform a simulation in the HOMER software, the expected peak electrical output of a hydropower turbine in Arandun on the Oshin River is about 200 kW in June, July, and August. In December and January, a minimum output of <10 kW was attained in some of the time steps of the simulation in HOMER software.

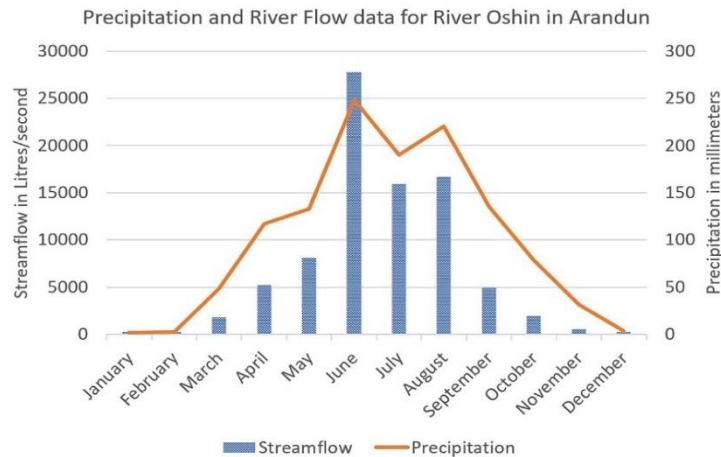


Figure 8. Average monthly streamflow and precipitation in Arandun

#### 4. CONCLUSION

The present study shows the potential of renewable energy microgrids in the community given existing resources at the location in Arandun, a community in Nigeria's middle belt. The three renewable energy sources of wind, hydropower and solar energy were examined in the study. MATLAB and HOMER were used in a multi-temporal analysis of renewable energy potentials to develop 39 separate (3 yearly and 36 monthly) probability distribution functions using MLE techniques for the solar irradiance uncertainty (using Lognormal distribution), hydropower uncertainty (using the Gumbel/extreme value distribution), and the wind uncertainty (using the Weibull distribution) at the location, which will be useful for future studies in the region. Furthermore, the effectiveness of the annual statistical parameters (such as shape, scale, and position parameters) of the distributions as a predictor of their various monthly values was investigated. It was found that for wind energy, there is a small loss of accuracy by using a uni-temporal (annual) approach to predict the performance across months, while for solar energy, there is almost no loss of accuracy. However, in the case of streamflow, the use of a uni-temporal statistic was found to be inappropriate for the prediction of the monthly MLE probability distributions, due to the wide variations in the quantity of rainfall and the probability of rainfall across months. Furthermore, while solar energy is very promising in the chosen location, hydropower potential on the Oshin River is seasonal and complementary to solar energy in the annual renewable energy cycle, while the wind energy potential is too low for the use of conventional horizontal axis wind turbines (HAWTs) at the location. The use of Savonius turbines or other vertical axis wind turbines (VAWTs) may be considered for wind energy applications in Arandun and similar locations in Nigeria's middle belt region.

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