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Techno-Economic Viability Assessment of Onshore Wind Power Generation in Southwest Nigeria

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Abstract

There is currently no commercial or mini-grid wind power generation in Southwest Nigeria, and previous research efforts generally consider the region non–feasible for a wind farm. A 20-year atmospheric meteorological data including wind speed was acquired for 23 evenly distributed stations strategically located in the mainland involving at least 3 stations in each of the 6 states that make up the zone based on historical and real time records from high resolution satellite, ground atmospheric data measurements from research institutions, weather records of private organizations, and individual sources. The wind energy data from satellite was compared and found to corroborate with other sources, given negligible variance. The viability of wind power generation was evaluated by applying empirical wind energy principles, proven technical and commercial feasibility measurement tools, such as the Techno-Economic Renewable Energy Viability Index (TEREVI), as well as HOMER and MATLAB Simulink simulations based on a 100KW direct drive wind turbine configurable with other energy generation technologies for mini-grid power generation. About 4.3% of southwest Nigeria has strong potential for commercially viable wind power generation at 10m AMSL and 87% at 50m AMSL altitudes, respectively. At 10m AMSL, the mean wind speeds range from 0.99m/s at Okitipupa to 6.29m/s at Obafemi Owode, with an average of 2.45m/s peaking between June and September, by which Obafemi Owode is the only site that passed the 3.5m/s threshold for commercial wind farm electricity generation. The wind energy potential generally shows strong localization with overall year – round 50mAMSL average of 3.76m/s while 75% of the year have values above 3.5m/s threshold ranging from 3.54m/s to 4.46m/s with Okitipupa, Ondo Town, Shagamu, and Osogbo being the only sites having below commercial threshold value while Obafemi at 7.2m/s has the highest.

Keyword: wind power mini-grid, Southwest Nigeria, TEREVI, wind turbine, commercial wind farm, wind energy conversion, Horizontal Axis Wind Turbine (HAWT), Direct Drive Wind Turbine

1.0. Introduction

Wind energy conversion system is a key contributor to green energy production and energy transition progress towards the 2050 Net Zero Energy target, with a cumulative annual growth rate of 9% and total global installed capacity of about 1140GW in 2024, which is projected to reach 190GW by 2030. While renewable energy contribution to global electric power supply is projected at over 45% in 2030 from 30% in 2023, wind power generation is projected to double in the global power mix from 8% in 2024 to 12% to 16% by 2030 (Ember, 2024; IEA, 2024; GWEC, 2025)

Poor and epileptic power supply is considered to be the singular biggest drawback in the actualization of Nigeria's vast human, natural, and economic potentials, being Africa's largest economy and most populated nation, having a paltry power generation of just around 4000MW for over 200million people, which is fast growing. Despite the huge promises presented by renewable energies, aside large hydroelectric power, no serious efforts has been made to strategically optimize all the renewable energy resources across Nigeria let alone implement the renewable energy components of the National Energy Masterplan over the years as more investments worth $25billion remains focused on fossil power generation such as gas and steam turbines while private organizations keep relying on diesel fired generators despite rising fuel prices thus heightening the cost of business operations and commodities generally (Adelabu, 2023; Akpan et al, 2023)).

Despite the high learning rate in wind energy conversion systems, there is yet to be an operational commercial wind farm or wind energy mini-grid in Nigeria. When it pertains to alternative electricity generation in Nigeria, wind energy conversion systems in Southwest Nigeria are rarely talked about if at all considered, aside from the fact that pilot projects are only being recently embarked upon at specific locations in North-East and North-West of the country where wind power potentials are significantly high and much more obvious given vast plains, high altitudes, and mountainous topographies (Akpohonor, 2023; Abubakar, 2025).

The need for a bottom-up approach to solving the electrification problem in Nigeria using various renewable energy alternatives is urgent, especially given the increasingly unsustainable cost of petroleum products for fuelling generators, which makes up the biggest source of power for industries and homes, as well as small and medium enterprises. Wind energy is a popular renewable electricity generation technology that has been in existence for millennia, but has yet to find root in Nigeria, except for micro installations of below 5KW units, some private properties serving curiosity or minor accessories, if at all needed. The Southwest of Nigeria is generally not considered favourable by most researchers and experts for wind energy power generation(Abubakar, 2025).

Onshore wind power generation is a very versatile and flexible electricity production technology, given it directly produces alternating current, has less reliance on energy storage, is dispatchability, is durable, is technically simple, and fair capacity factor among other things. Wind power generation is one of the lowest-hanging fruits when it comes to harnessing renewable energy potentials for power, aside from being a great synergy with solar and conventional sources. In terms of electricity cost, wind electricity production cost tends to reduce by about 15% for every doubling of capacity which is a strong incentive for larger scale installation particularly for locations with above average potentials by which the power output increases with windspeed from cut – in to cut – out values (EWEA 2023; Better et al, 2021).

Hence, the exploration and exploitation of wind energy for power generation in identified viable high wind speed locations is key to cost–effective optimization of locally available natural resources for a sustainable clean energy solution, which is tied to the attainment of most Social Development Goals and general infrastructural growth locally and globally. This is in addition to the fact that wind farms generally do not prevent the use of land for alternative activities and also make it easy with collocation with other power generation sources (Abubakar, 2025; GWEC, 2025).

Due to the great role played by wind energy power generation in many climes both for energy transition and boosting power supply, there is a need for an in-depth study of wind power generation potentials in Nigeria beyond the negative conclusion of most past research efforts for South-West Nigeria given its significantly varied mainland topographies. Due to the relative scantiness of wind energy data particularly for southwest Nigeria due mostly to very limited recording stations, this study is greatly focused at ensuring a very representative information by expanding the number of data sites from the 3 available in the entire Southwest by the Nigeria Meteorological Agency (NIMET) to 23 dues to the tendency of wind speeds to very greatly with local topographies, vegetations, hydrology, climate, and anthropogenic structures among other thing(EIA, 2023;IEA, 2024; SA, 2024; Altieri, 2025).

Wind energy has been harnessed for millennia, mostly in the form of windmills for ship sailing, agriculture, and water pumping of water among other possible applications. Wind power generation is the system of electricity production using a wind energy conversion system called a wind turbine. Wind turbine is a rotordynamic machinery that converts the kinetic energy of wind flow into rotational kinetic energy of the turbine blade assembly, coupled directly or indirectly to an alternator from which electricity is produced and distributed. Wind turbines are designed as either Vertical Axis Wind Turbines (VAWT) or Horizontal Axis Wind Turbines (HAWT) for the shaft and coupler orientation to the generator. Hence, VAWT and HAWT designs extract energy from the momentum of wind via drag and lift aerofoil mechanisms, respectively. The blade profiles of wind turbines are intentionally designed to optimize interaction with impinging wind and by so doing, extract as much energy as possible. The power generated by a wind turbine is in direct proportion to the cube of the wind speed and swept area of its blades (EIA, 2023; SA, 2025)

While VAWT technologies require a lower cut-in wind speed for power generation, structural limitations due to excessive vibration and high bending moments greatly limit their sizes and thus are rarely satisfactory for operations beyond 10 kW capacities. This makes HAWT the most common and popular design for commercial-scale operations with sizes ranging from 1 kW to 1.5MW or even more and rotor diameters up to well over 100m. With advances in metallurgy, material science, aeronautics, and simulation technologies, more efficient and larger turbines are increasingly being unveiled such that the unit capital expenditure per kW as well as weighted average levelized cost of electricity have fallen well over 65% in the last 20years (SA, 2024).

HAWT is configured either by a Direct Drive Mechanism or by a Gear Drive Mechanism. In the Direct Mechanism, the blade-rotor assembly is directly coupled to the alternator enclosed in the nacelle, while for the Gear Drive Mechanism, the blade and rotor assembly is coupled to a gearbox, which is in turn coupled to the alternator. The gearbox. The gearbox increases or reduces speed by design and thus is most suitable for large turbines, while direct drive is much more suitable for smaller units, like in the 100 kW hypothetical design wind-powered mini-grid systems used for this study. In order to optimize wind energy capture, a HAWT is designed as either upwind or downwind, which operates by facing or backing the prevailing wind, respectively. Further to this, the yaw mechanism ensures the turbine blade is in line with the prevailing wind by either facing it directly or backing it concerning the blade profile for more optimal wind energy harvest ((Bhatia, 2024; Cheng, 2014).

The Federal Government has completed but yet to commission due to security reasons a 10.175MW wind farm at Lamba Rimi in Kastina State, North – west, Nigeria consisting of 37 units of 2 – blade 275KW Vergnet turbines with rotor diameter of 32m installed at 55m hub height AGL (Salisu, 2013). The GEV MP C 275/32/2 Vergnet wind turbine mode is a medium has 12.0m/s rated windspeed, 3.5m/s cut – in windspeed, 25m/s cut – out windspeed, and 85m/s survival windspeed with a Wind Class of IEC 11a (Vergnet, 2006). The project contractor is a French company, Vergnet and was funded by the Japanese International Cooperation Agency (JICA). Though started in 2006 by the Kastina State Government but was taken over by the Federal Government in 2008 when the erstwhile governor of the state emerged President of Nigeria.

Not far away from South – West Nigeria, Senegal, a fellow West African country in 2020 commissioned its 158MW wind farm at Taiba N'Diaye made up of 46 turbines executed by Vestas, British renewable energy company after achieving financial close in 2018 to generate electricity for 2million people and cut 300,000MTCO$_2$, which in effect enabled the country to hit the 30% renewable energy target while at the same time meeting about 30% of the nation's energy needs(Peyton, 2020).

Other planned wind energy projects in Nigeria includes : 100MW Vwei Kuru Wind Power Project, Plateau State by JBS Wind Power Limited; 10MW Lekki Coastal Wind Power Project, Lagos by Price Waterhouse Coopers Limited(PWC); 8.5MW Ado Ekiti Wind Power Project, Ekiti State by Enersys Limited; 10MW Kastina Wind Farm 2 by Federal Ministry of Power (Federal Ministry of Environment, 2017; CRET, 2015) and CGC Wind Power Project, 674 Cadastral Zone, Lugbe. Abuja by CGC Nigeria (Federal Ministry of Environment, 2015; CRET, 2015). The Beaufort Scale is as shown in table 2.1.

2.0. Literature Review

Akporhonor et al (2023) assessed and estimated the wind energy potential in Nigeria for exploration and exploitation using various criteria and data. Their finding shows medium and low potentials with emphasis for development on less than 20% of areas in the country suitable for wind energy development. However, the study was greatly limited in the number of data stations and sources, which leaves lots of issues to be addressed to adequately project a fair picture of wind energy potential in the country. The limited information resulted in a situation of overgeneralization, thus necessitating further studies.

Idris et al (2020) and Okonkwo et al (2021) analysed the status of the development of wind energy in Nigeria, which shows very low interest and development efforts by both decision makers and policy makers, giving rise to little information and understanding of the technology and resulting in no notable commercial development despite the exigency of energy in the country and the need to tap renewable energy resources.

Abubakar (2025) carried out studies on the feasibility of a wind power generation system by a detailed analysis of the supply chain in Nigeria. His findings exposed the need for adequate regulatory provisions and the need for concerted efforts and consciousness regarding the opportunities presented by wind energy systems to the problem of power shortage in Nigeria. The prospect in a mix of opportunities and challenges that needs more scientific information and studies for better commerciality. Their works generally reflect the mindset of both public and non-public sector towards renewable energy prospects generally and the strategies required to overcome the barriers to engender clean development.

Adaramola et al 2012 carried out a Techno-Economic Evaluation of Wind Energy in South-West Nigeria using 8 stations based on 37-year data, with Lagos showing the best point for economically applicable electricity at 70m hub height due to the coastal effect on windspeed. However, the data space was very limited given the vastness of in landmass of Southwestern Nigeria. In addition, the dataset was over 30years older than the study, which reduces the practicality of the result due to significant changes in climatic conditions over the last few decades, even if marginal.

Nze-Esiaga and Okogbuem (2014) studied wind energy feasibility in Southwest Nigeria based on 51years of data and 5 locations within Southwest Nigeria, which suggested higher hub heights for better wind energy viability. However, this study leaves out some critical information, especially with uneven site selection and very limited data stations, which do not actually reflect the region. The is also followed by the fact that studies like previous research were biased on perceptive high windspeed site selection among other things =.

Similarly, Amutah (2025) assessed wind energy potential in Southwest Nigeria, but the results were based on a single station and presented very high values of wind speed, not consistent with most other research data, given the very high average results. This necessitates further studies, even in knowing the temporal and highly localized nature of windspeed variation. This also highlights the need for sufficiently long period data and a fairly sizable number of stations for balanced and detailed assessment

Sanusi (2012) estimated the wind energy potential in Southwest Nigeria and found it to be quite low with fair prospects, even if necessary, research and development efforts are made. Okeniyi et al (2015), assessed wind energy potentials in selected sites across Nigeria's 6 geopolitical zones. Also, Fatigun et al (2020), carried out studies on wind technology, potential, and energy cost in Ikeja Lagos for commercial viability assessment which shows some good prospects but does not present a conclusive elucidation given the limited data points and period of acquisition for adequate scientific judgement given the seasonal and diurnal variation of wind energy flux.

3.0. Onshore Wind Power Principles and Technologies

Wind is defined as air in motion while wind energy conversion system(WECS) is any technology designed for converting wind the energy of moving wind (wind energy) into electricity aside non power uses such as for windmill in agriculture and water pump, sailing and scarecrow among several existing and possible applications including hydrogen energy storage. Wind energy is one of the fasted growing means of power generation in the world and thus expected to form a key cornerstone stone towards achieving full energy transition and carbon neutral with a projected contribution of about 1/5th of global generation and consumption by 2050 in the same period the UNFCCC has targeted for Net Zero Energy Transition with investments of about $30billion and counting (Alagbada, 2022).

The higher a windspeed, the higher the power a turbine can generated from it with respect to its cut – in windspeed and cut – out windspeed as well as the rated windspeed. Once cut – in windspeed is attained, a wind turbine's power output increases steeply and reaches peak power generation at the rated windspeed, which is about 11m/s to 15m/s (Neil and Hashemi, 2018). The cut – in windspeed is about 3.5m/s and is the minimum windspeed at which a turbine starts generating electricity while the cut – out windspeed (about 25m/s) (Neil and Hashemi, 2018) and is the windspeed at which a turbine's alternator has reached its peak power rating and can no longer continue but has to be automatically disconnected at that point in order to avoid electrical and mechanical damage.

Windspeed increases with mean height above ground level (Egwaile et al, 2020) and is typically highest at the poles, cold seasons (winter and harmattan), at nights, vast plane lands, high points (hills, plateaus, and mountain ranges), vast water surfaces (lagoons, oceans and seas) and midpoints between two high points and coastlines. Hence windspeed can vary a great deal even within a city (Longo et al, 2020). Thus, wind turbines need to be installed without windbreaks such as trees and high structures in reasonable distance ahead of it in the direction of the prevailing wind so as not to reduce the windspeed and consequently its power outputs in similar manners that turbines in wind farms must be positioned with adequate clearance between units while environmental factors like bird migration paths needs to be considered (in order to avoid bird deaths).

Exact best wind turbine spacing is not 100% certain as it varies with windspeed, topography, atmospheric boundary layer effects and turbine size among other possible factors. However, the common rule of thumb is based on the 7D X 5D Principle of spacing a wind turbine with 7 rotor diameters as clearance from the next in front or behind and 5 rotor diameter clearance from the next beside it left or right (Salisu,2013).

For general optimal spacing, a wind turbine should be installed at least 10meters higher than its nearest structure and at least 200meters away from its nearest upstream structures less than a vertical clearance of 10m below the lowest tip of its blade above ground level (AGL) while for wind farms, turbines should be arrayed such that each turbine is at least 2.5 rotor distance clearance to the one beside(parallel wind farm configuration) it or at least 5 rotor diameter from the one upstream or downstream of it (series configuration) in order to ensure adequate undisturbed upstream wind flow(so as not to reduce power output), reduced crowd noise, and minimized resonance vibration (which leads to early waring out of turbines) (Duval, 2021 ; Gaughan, 2018 ; and Meyers, 2012) though for locations with very high windspeeds, this spacing be reduced with respect to surface roughness and atmospheric boundary layers. However, the acreage taken up by wind turbine installation are available for other human uses including food crop and pastoral farming, ponds, water treatment facility, resorts and recreation, sporting activities, flora and fauna as well as development of non – interfering physical structures.

Wind farm are installed in any of 4 different configurations. In series string wind farm configuration, the turbines are arrayed in queue against the oncoming wind from upstream to downstream. Parallel string configuration are arranged side by side each facing the prevailing wind direction with no unit upstream or downstream of it. Multiple string configuration is a matrix (of either series of parallel) consisting of multiple strings arrayed in row and columns. Wind turbine cluster is a configuration in which each turbine unit is neither in series or parallel position to the rest but just distributed in no definite order within an area of land. WECS module for power generation are called wind turbines. Wind turbine technology come in varying design, working principles and capacities by which they are also classified. Wind turbines are designed based on 2 broad technologies: HAWT and VAWT.

The main components of a wind turbine are:

i. Rotor - blade and hub assembly or as a single cast especially for micro scales

ii. Nacelle - a cylindrical housing coupled to the rotor shaft horizontally for HAWT and vertically for VAWT and contains the alternator, bedplate and ancillary components, sensors and bearings

iii. Mechanical Transmission System or Drive Train - usually composed of gear box to increase alternator speed, shafts and couplings, bearings and mechanical brake

iv. Yaw Mechanism – a uniaxial join for 360◦ rotation in order to optimize blade speed by constantly turning the blade to always face the direction of wind (in the case of upwind HAWT) or back the direction of the prevailing wind (in the case of downwind HAWT).

v. Tower and Basement Structure – the stem of the wind turbine suspending the blade from the ground. The hub height determines the blade height above the ground given that wind speed increases with height above ground level (AGL)

vi. Electrical Power Conversion and Transmission System – composed of the wire and cabling, transmission, switchgear, and power electronic converters etc.

Wind turbines are basically categorized as small, medium and large. Small turbines range in rotor diameter and power rating of 0 – 49KW and 1 to 19m respectively, medium wind turbines range from 50Kw to 999KW and 20m to 60m while large turbines are greater in capacities and radius (Gipe, 1999 and Spera, 1994). In practice, single large onshore wind turbines are usually of power generation capacity less than 5MW with typical hub heights of 60m to 120m while single offshore wind turbines of well over 10MW generation capacities do get designed and built but hardly up to 15MW with heights up to 260m or more and blade lengths up to 100m with probability of further growth in component sizes with more engineering innovations breaking barriers owing to the high pace of wind turbine technological advancement.

HAWT is designed as either upwind(turbine rotates by yawning itself facing the direction of oncoming wind always) or downwind(turbine rotates by yawning itself backing the oncoming wind always) in operational orientation which are all by technological principles based on lift and requires wind speed of at least 3.5m/s for power generation while VAWT is primarily based on drag force with some types using both drag and lift based on the blade profile and axial orientations among other things and requires cut – in wind speed of at least 3m/s.

Though VAWT are about 15% more efficient than HAWT (Hansen et al, 2021), due to torsional ripples effect now addressed by the helical sweeping blade design by Gorlov and bending moment problem on shaft, there is limitation to the capacity than can be built (Battisti et al, 2016). Designed to face the wind transversely with its rotor axis vertical, VAWT are of different types which are variants of 2 basic design: Lift Type (Darrieus Turbine) and Drag Type (Savonious). Popular derivative designs include Gorlov helical (Savonious), cycloturbine (Darrieus), harmony turbine (Savonious) and H – Rotor or giromill turbine (Darrieus) among others.

While the nacelle (cylindrical compartment containing alternator and gearbox) HAWT is located at the height of the rotor, that of the VAWT is located at floor level which enhances quick and easier maintenance and does not need yaw mechanism or sensor for directional change while also able to generate under turbulent winds. Savonious VAWT is based on drag force while Darrieus, giromill and cycloturbine are based primarily on lift and partially on drag though operates at lower Tip Speed Rations (TSR) and efficiency compared to Darrieus but far more reliable and structurally tough thus best suited for distributed generation in urban centers (Longo et al, 2021). The low efficiency of Savonius turbine is due to the fact that only half of its tongue generated is positive given that as one half turns with the wind, the other half turn against it. Though the negative torque effect is reduced with helical designs which evenly distributes the torque ripples around the rotor.

Being a lift driven turbine, Darrieus type is built with a number of aerofoils (swollen wings) attached to the rotor which thus makes the turbine lighter due by creating lift hence generating higher force leading to greater blade speed compared to the Savonious design and the torque ripple it generates can be reduced and managed by redesigning the aerofoil in helical shape. HAWT are the most popular and techno – economically applicable for commercial scale wind power generation due to their structural flexibility allowing for large power harvest by single units up to well over 5MW though demand higher compared to VAWT that is difficult to construct and hardly techno – economically viable beyond 10 to 30KW capacity.

Though a wind turbine assembly is responsible for about 80% of total CAPEX, based on various reports, wind turbine tower accounts for 27% of a turbine unit's cost while the rotor/blading, gearbox, power converter unit, and transformer costs are responsible for 22%, 13%, 5%, and 3.6% respectively (EWEA, 2009; NREL Report, 2019). A modern wind turbine is usually constructed with composite or optimized best – for – purpose material uses for various components typically in the proportion of 66%/78%, 11%/16%, 5%/17%, 1%, and 0/2% for steel, fiberglass or plastic material, iron, copper, and aluminum respectively (Yacoubou, 2022). Hence, for commercial operations such as land based and offshore wind farms, HAWT technology is the standard. However, due to high windspeed requirement and wide instantaneous variations in windspeed, wind turbines typically have average nameplate capacity factor (also called load factor) of about 10% to 40% and high harmonic emissions needing synthetic inertia for smoothen prior to wheeling to the grid.

However, capacity factor determination is not purely at the whims and caprices of weather conditions as techno – economic decisions creates rooms for either increasing or decreasing capacity by virtue of selecting the best balancing point between CAPEX and revenue. For example, longer blade means larger swept area and consequently higher power output but the turbines electrical and electronic ratings also determine how much power it can generate at given windspeed and the higher the number of higher windspeed, the higher the capacity factor. Thus, for low electrical and electronically rated turbines, power can be generated for longer hours in a year and at lower windspeeds as well as cheaper CAPEX and transmission cost than for a higher rated turbines but only lesser percentage of its nameplate capacity will be generated on average for the same size and capacity while a high electrical and electronics rated turbine will generate higher power percentage of its nameplate but only for few hours in a year.

With average windspeed between 2m/s and 4m/s, Nigeria's wind energy potential is about 150,000TWh/year (Shaaban, 2013) with most of the country's coastal regions having windspeed of 4m/s to 5m/s and up to 8m/s in the mountainous areas (Chineke, 2009, Fadare, 2010). The Beaufort Wind Force Scale or simply the Beaufort Scale is a numerical indicator that categorizes windspeed and its consequential force level on a scale of 1 to 17 in full but 1 to 12 in nominal conditions in ascending order from calm to hurricane as shown on Table 3.1 (Rutledge et al, 1996).

Though there are different sites with very high windspeed in south – west Nigeria just like obtains in all regions of the country, generally, the windspeed regime in southern and Northern Nigeria is 1 – 3 and 3 – 4 in the Beaufort Scale as in Table 4,1, thus informing the need for more comprehensive ground data coverage such as large number of stations for more specific suitable location, introduction of wind power map as well as wind energy code for buildings and the creation of enabling legislations concerning individual renewable energy sources rather as a whole(Ajayi, 2010).

4.0. Methodology

This study was carried out by the selection of 23 evenly distributed stations across the mainland of Southwest Nigeria, which also takes into account geographical and topographical diversity in order to optimally capture localized wind energy flux variation across various vegetation zones and elevations, as well as landforms. Thus, the site selections captured the key natural variables influencing energy potentials such as elevation, vegetation, hydrology, and climate.

Secondly, a 21-year hourly wind energy speed data from beginning from year 2000 to 2021 was acquired from the National Aeronautics and Space Administration (NASA) Langley Research Center (LARC) and the National Renewable Energy Laboratory (NREL) satellite high-resolution altimetry data record as the primary data. Similar wind speed information was also obtained from 3 stations of the Nigerian Meteorological Agency (NIMET), some multinational oil companies, and local research institutions. Ground wind speed measurements with an anemometer in combination with a homemade 1.2 kW HAWT were carried out.

The ground wind speed measurements of 12 random locations, together with NIMET's 3 Stations wind data, as well as those from multinational oil companies and research institutions, were limited in coverage and time length thus were used as a comparator for congruence with the LARC 21-year wind speed record. A monthly mean for the hourly 21-year LARC record was calculated. The LARC wind energy data strongly and conservatively corroborate the other mean monthly wind speed data sources, aside from a 3.4% wild deviation. Hence, the LARC was adopted as the single data source for the research calculations, modeling, and simulation after the comparative data integrity test.

A hypothetical Synchronous Permanent Magnet Generator (SPMG) Direct Drive Wind HAWT-powered 100 kW interoperable mini-grid system was designed. The TEREVI and TELCOE were computed based on Okwori (2025; 2025) for TEREVI and TELCOE development and assessment for the Sub-Saharan African renewable energy mini-grid scenario. MATLAB Simulink and HOMER simulation were also carried out, in which the best COE values were obtained based on Okwori (2025). Figure 4.3 shows the model mini-grid system design configuration. Figure 3.4 shows the workflow of the onshore wind power generation techno-economic assessment process.

HAWT was chosen for the design due to the structural and capacity limitations of VAWT. The Direct Drive HAWT was selected over the Gear Drive HAWT for several technical, economic, and environmental reasons. The Direct Drive HAWT is a low-speed high-torque turbine hence has is necessarily of larger and heavier construction using rare earth permanent magnet generator. Conversely, the Gear Drive HAWT is of high-speed electrical excitation current generator and thus smaller in size and weight.

While in Direct Drive HAWT, the high torque low speed rotor-shaft is connected directly to the alternator, in Gear Drive HAWT, a low torque high speed shaft links the rotor-shaft to the Gear Drive and then to the alternator. Gear Drive HAWT also called variable speed wind turbine has lower capital cost, is lighter, has a higher power-to-weight ratio, requires less space, and generates even with wide varying wind speeds due to the gearbox, but has lower conversion efficiency and higher failure rate cum maintenance cost due to a larger number of moving parts aside the complexity of gearbox technology and repair cost leading to dearth of qualified technicians and longer downtime.

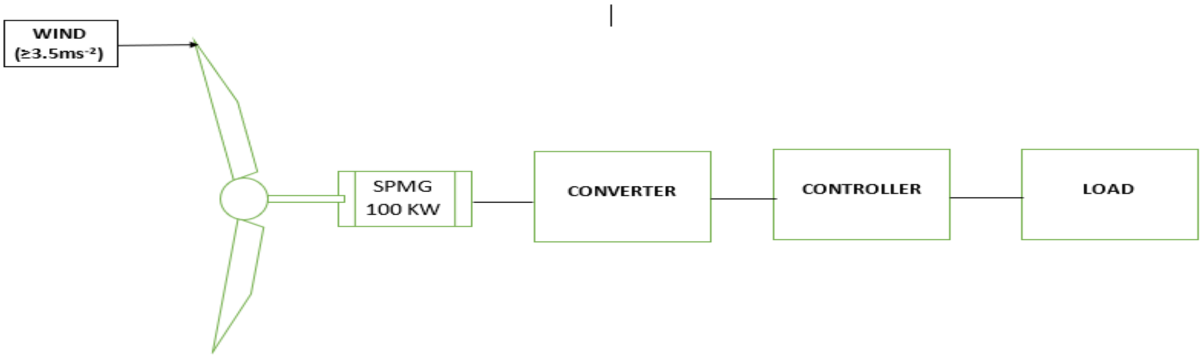

Fig. 4.1: powertrain of the mini-grid direct drive SPMG HAWT

As the powertrain shown in Figures 4.1 and 4.2, Direct Drive HAWT is technically simple in construction and maintenance, more reliable, less noisy, has higher conversion efficiency, has more constant power output even in areas with fluctuating wind speeds, lower operating cost, and lesser amount of manufacturing construction materials cum carbon emission, which makes more environmentally sustainable. It is also much more suitable for moderate and marginal wind energy flux environments, in addition to being more rugged and reliable, with rare cases of failure. In addition, SPMG Direct Drive HAWT is a fast-evolving technology with great future improvements being recorded, making them progressively lighter and thus more suitable for rural mini-grids, given remote locations and associated logistical challenges. SPMG Direct Drive HAWT has a cut-in wind speed of about 3.5m/s and cut-out wind speed of about 25m/s, and a generator speed ranging from 8RPM to well over 1500RPM, and voltages of 380 – 1410VAC for 100 kW/150 kW units in the market.

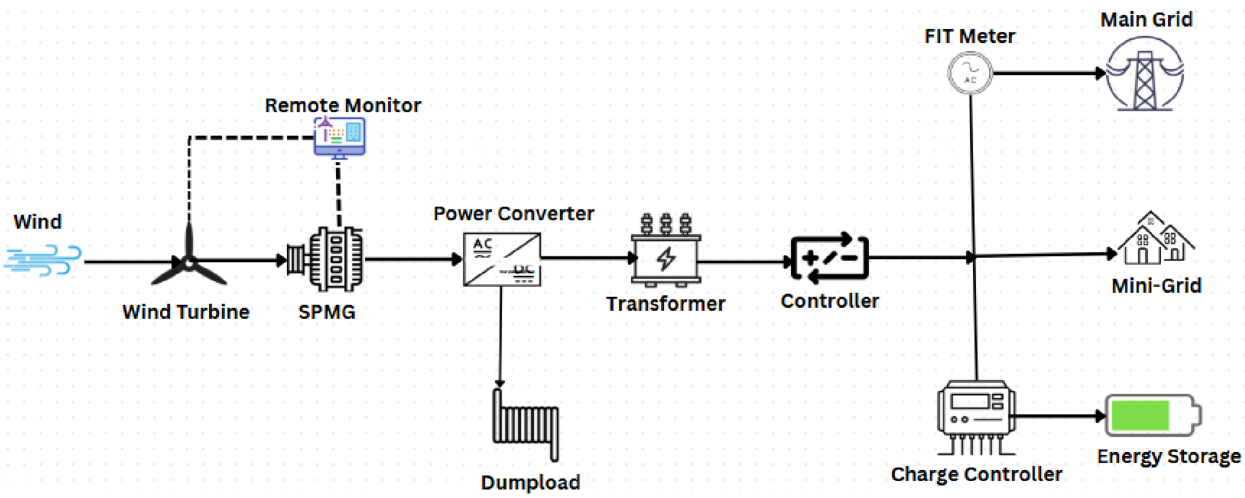

Fig. 4.2: The Direct Drive SPMG wind turbine schematic in interoperable mini-grid configuration

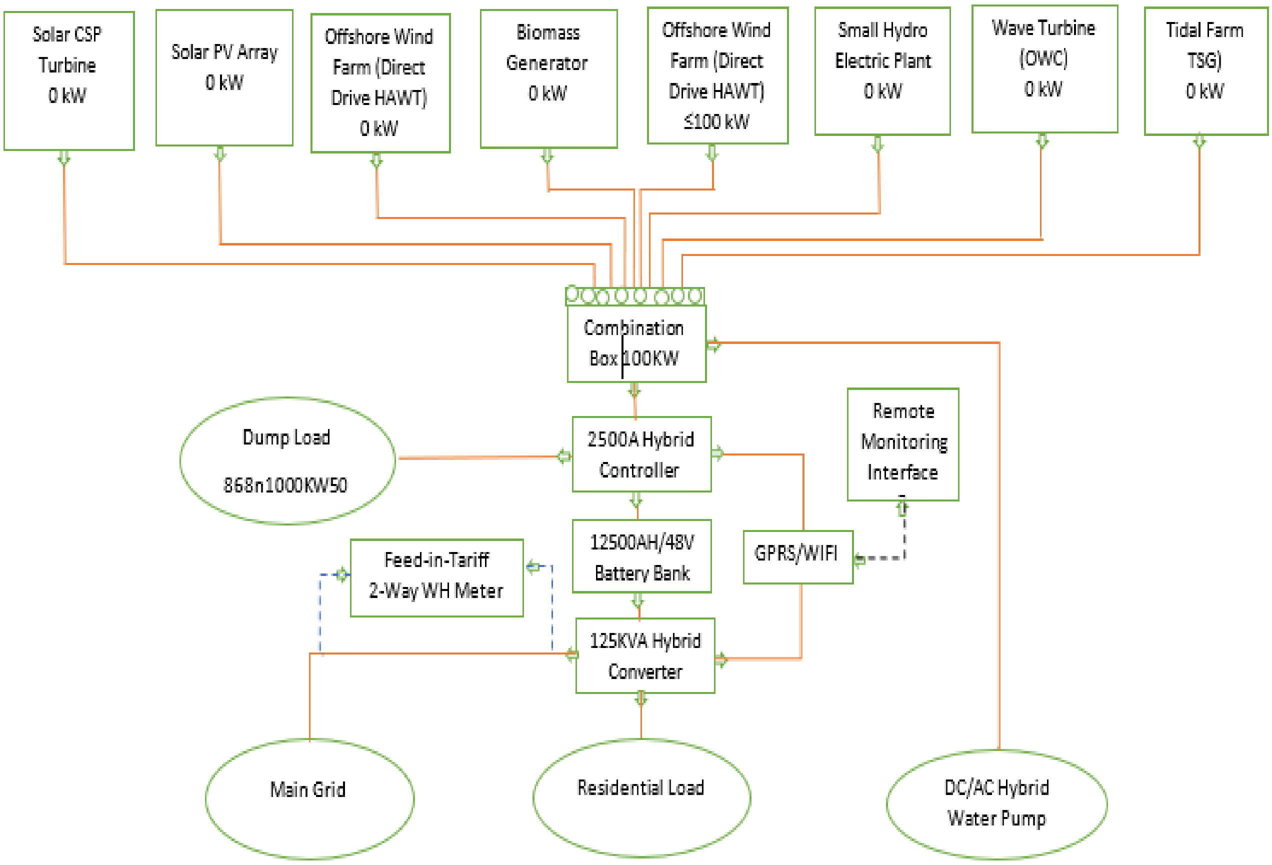

Fig. 4.3: Direct Drive SPMG wind turbine in hybrid renewable energy mini-grid configuration

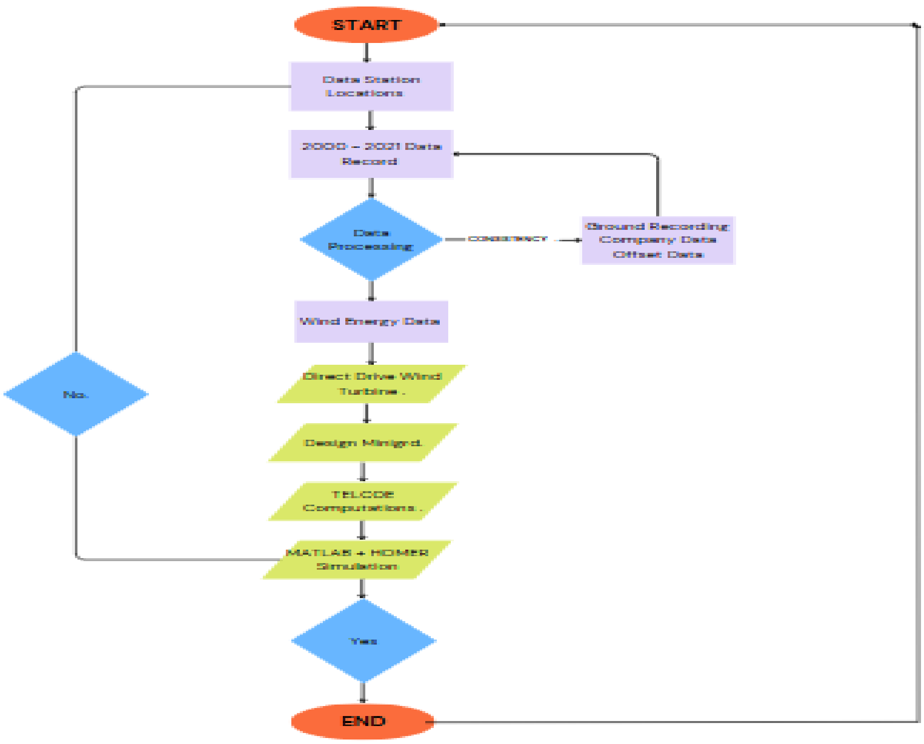

Fig. 4.4: process workflow of the onshore wind turbine viability assessment

Beaufort Scale	Windspeed (m/s)	Physical Condition
0	0	Calm or still enough such that smoke visibly rises vertically
1	0.3 – 1.4	Light wind such that visible smoke drifts in the direction of the wind
2	1.7 – 3.1	Wind is able to move flags and be felt on hairs and faces
3	3.3 – 5.3	Mild breeze that waves flags and hairs or dried cloths on washing line
4	5.6 – 7.8	Mild breeze that scatters papers and leaves as well wet or dry clothes on washing line
5	8.1 – 10.6	Fresh breeze swaying small trees, and in which whitecaps form in waves, and falling fruits on trees
6	10.8 – 13.6	Strong breeze is damaging or preventing the use of an umbrella and felling tree branches
7	13.9 – 16.9	Moderate gale swaying large branches of trees, flying objects with reduced visibility, and makes it difficult to walk in the open due to significant push or pull impacted by the wind
8	17.2 – 20.6	Fresh gale in which even tree large branches and twigs are broken from trees
9	20.8 – 24.4	Strong gale that pulls roofs and thatches off buildings
10	24.7 – 28.3	A whole gale that uproots trees
11	28.6 – 32.8	Storms create widespread destruction of buildings, vegetation, and infrastructure with little visibility
12	33.1 - 61.1	Category 1 Hurricane, Category 1 Tornado: widespread destruction

Table 4.1: Beaufort showing wind energy class. Saucer (2003)

Wind turbine power output is directly proportional to the cube of the prevailing windspeed V, the swept area A, and the wind's density $\boldsymbol{\rho}$, and mass $\dot{m}$, given the theoretical power is derived from the kinetic energy E_K of wind by the following relations:

$$\dot{E}_K = \frac{1}{2}\dot{m}V^2 \quad \text{...........4.1}$$

$$\dot{m} = \rho AV \quad \text{...........4.2}$$

$$\dot{E}_K = \frac{1}{2}\rho AV^3 \quad \text{...........4.3}$$

However, in reality, the actual power from a wind turbine is only a fraction of the gross windspeed, factored by the coefficient of power (C_P) which is a function of the blades design efficiency determinants such as Tip Speed Ratio (λ), pitch angle or blade angle (**β**) among other things thus:

$$\dot{E}_K = \frac{1}{2}\rho AV^3 C_P(\beta, \lambda) \quad \text{........4.4}$$

The generic equations relating the C_P, β, and λ is taken as expressed by Heir (1998) thus for modeling the onshore Direct Drive SPMG turbine characteristics:

$$C_P(\lambda, \beta) = C_1(\frac{C_2}{\lambda_i} - C_3\beta - C_4)e^{-\frac{C_5}{\lambda_i}} + C_6\lambda \quad \text{.........4.5}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad \text{........4.6}$$

According to Betz's Law, the maximum convertible wind power by a turbine is 0.59% of the theoretical wind power and factoring the generator(alternator) efficiency or power factor (η_G). Hence: given $C_{Pmax} = 0.59$ therefore:

$$\dot{E}_K = \frac{1}{2}\rho A V^3 \eta_G C_P(\beta, \lambda) \quad \text{.........4.7}$$

Given the that the angular speed of the blade is ω, Torque T and the turbine rotor radius is R:

$$\boldsymbol{\lambda} = \frac{Blade\ Speed}{Windspeed} = \frac{\omega R}{V} \quad \text{.........4.8}$$

$$Toque = \frac{Power}{Angular\ Speed} = \frac{\dot{E}_K}{\omega} \quad \text{...........4.9}$$

Knowing that windspeed increases with height above ground level, the Power Law expression enables the determination of relative windspeed at given height with respect to measured values (Oyedepo et al, 2012; Egwaile, 2020):

$$V = V_m(\frac{h}{h_m})^\alpha \quad \text{.........4.10}$$

Where V, V_m, h, h_m, **α** are the velocity at proposed height, measured velocity, proposed height, measured height and Hellman Exponent (Coefficient of Friction)

The resultant wind velocity $\vec{V}$ of oncoming wind striking the wind turbine blade is at maximum when the blade's orbital(azimuthal) angle ψ = 0 and minimum at ψ = 180.

Given that the blade radius is $\vec{R}$ and its angular speed is $\vec{\omega}$ with the upwind speed as $\vec{U}$ the vectoral windspeed is will be the sum of the sum of $\vec{U}$ and $-\vec{\omega}\ \vec{R}$ thus

$$\vec{V} = \vec{U} + \left(-\vec{\omega}\ \vec{R}\right) \quad \text{.........4.11}$$

From the blade wind flow schematic diagram, the tangential velocity of the turbine V_H is with respect to the angle of attack **α** (angle between the wind and the blade chord) thus:

$$V_T = UCos\psi + \omega R \quad \text{........4.12}$$

While the perpendicular velocity of blade due to wind striking normally is on it is:

$$V_N = Usin\psi \quad \text{.........4.13}$$

According to (Islam et al, 2008) the resultant velocity of the wind is:

$$V = \sqrt{V_T^2 + V_N^2} \quad \text{........4.14}$$

Invoking the TSR, we get

$$\lambda = \frac{\omega R}{U} \quad \text{.......4.15}$$

Hence from Guilherme Silver we have:

Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 47 No. 03 (2026)

$$V = U\sqrt{1 + 2\lambda Cos\psi + \lambda^2} \quad \text{………4.16}$$

$$\alpha = Tan^{-1}\left(\frac{V_N}{V_T}\right) \quad \text{………4.17}$$

Which (El Kasmi et al, 2008) reduces to:

$$\alpha = Tan^{-1}\left(-\frac{Sin\psi}{Cos\psi + \lambda}\right) \quad \text{……….4.18}$$

Given C to be the blade chord's length and $\mho$ as the kinematic viscosity, the mean Reynold's number is given by Guilherme Silver as:

$$R_e = \frac{VC\sqrt{\lambda^2+1}}{\mho} \quad \text{……..4.19}$$

Given the drag (force acting across the net relative wind on the blade) to be D, the lift (force acting along the net relative wind) to be L, the tangential force (horizontal component of the wind force on blade) to be GT and the perpendicular component of the wind force on the blade to be GN; the respective force coefficients become:

$$C_L = \frac{L}{0.5\rho AV^2} \quad \text{………4/20}$$

$$C_D = \frac{D}{0.5\rho AV^2} \quad \text{………..4.21}$$

$$C_N = \frac{G_N}{0.5\rho AU^2} \quad \text{………4.22}$$

$$C_T = \frac{G_N}{0.5\rho AU^2} \quad \text{……..4.23}$$

5.0. Onshore Wind Speed Data for South–West Nigeria

The wind energy data are obtained throughout 3years from 2020 to 2023 from both historical archive and real-time value in comparison and corroboration with between satellite recording and ground recording from different stations as shown in table 5.1 and table 5.2 which include research institutions and private project data including NASA, Langley, Earth Data, NIMET, Copernicus, and Surf-forecast.com. Table 5.3, 5.4, 5.5, and 5.6 show the mean variation in wind power potentials across the various stations at respective hub heights above mean sea level (MSL).

AVERGAE ONSHORE WINDSPEED AT 50M ABOVE GROUND LEVEL FOR STRATEGIC LOCATIONS ACROSS SOUTH-WEST NIGERIA 2000 – 2021													
LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
OBAFEMI OWODE	7.17	7.66	7.95	7.64	7.61	7.59	6.78	6.38	6.94	7.03	6.71	6.71	**7.18**
ABEOKUTA	3.18	3.58	3.87	3.88	3.59	3.84	4.42	4.58	3.80	3.20	2.74	2.75	**3.62**
ADO EKITI	3.46	3.53	3.72	3.81	3.51	3.63	3.99	4.11	3.30	2.83	2.62	3.00	**3.46**
IGBOHO	4.34	4.26	4.55	4.91	4.60	4.49	4.67	4.74	3.73	3.27	3.12	3.81	**4.21**

OKITIPUPA	2.34	2.53	2.55	2.45	2.27	2.44	2.72	2.83	2.49	2.17	1.94	2.00	**2.39**
SNAKE ISLAND	3.26	3.91	4.30	4.24	3.90	4.43	5.15	5.28	4.54	3.71	3.11	2.86	**4.06**
AKOKO	3.99	4.11	4.40	4.56	4.22	4.27	4.57	4.66	3.78	3.31	3.11	3.50	**4.04**
AKURE	3.46	3.53	3.72	3.81	3.51	3.63	3.99	4.11	3.30	2.83	2.62	3.00	**3.46**
IBADAN	3.18	3.58	3.87	3.88	3.59	3.84	4.42	4.58	3.80	3.20	2.74	2.75	**3.62**
IGBO ORA	3.54	3.82	4.13	4.25	3.98	4.12	4.62	4.76	3.84	3.28	2.82	3.05	**3.85**
IJERO EKITI	3.76	4.04	4.51	4.80	4.39	4.38	4.73	4.83	3.74	3.27	3.05	3.28	**4.06**
IKIRE	3.11	3.25	3.46	3.55	3.30	3.45	3.86	3.98	3.20	2.67	2.35	2.65	**3.24**
IKORODU	2.97	3.55	3.88	3.83	3.56	4.03	4.66	4.76	4.11	3.41	2.89	2.64	**3.69**
ILA ORANGUN	3.76	4.04	4.51	4.80	4.39	4.38	4.73	4.83	3.74	3.27	3.05	3.28	**4.06**
ILESHA	3.46	3.53	3.72	3.81	3.51	3.63	3.99	4.11	3.30	2.83	2.62	3.00	**3.46**
ISE EKITI	3.99	4.11	4.40	4.56	4.22	4.27	4.57	4.66	3.78	3.31	3.11	3.50	**4.04**
ISEYIN	3.54	3.82	4.13	4.25	3.98	4.12	4.62	4.76	3.84	3.28	2.82	3.05	**3.85**
ONDO TOWN	2.77	2.83	2.84	2.79	2.58	2.74	3.06	3.16	2.67	2.29	2.08	2.38	**2.68**
OSOGBO	3.11	3.25	3.46	3.55	3.30	3.45	3.86	3.98	3.20	2.67	2.35	2.65	**3.24**
OWO	3.51	3.56	3.69	3.72	3.44	3.60	3.97	4.06	3.35	2.86	2.60	3.02	**3.45**
SHAGAMU	2.96	3.28	3.52	3.56	3.32	3.57	4.10	4.26	3.56	2.97	2.51	2.54	**3.35**
LEKKI	2.97	3.55	3.88	3.83	3.56	4.03	4.66	4.76	4.11	3.41	2.89	2.64	**3.69**
MEAN	**3.54**	**3.79**	**4.05**	**4.11**	**3.83**	**4.00**	**4.37**	**4.46**	**3.73**	**3.23**	**2.90**	**3.09**	3.76

Table 5.1: 21-year mean monthly windspeed at 50mAMSL for the 23 stations

AVERGAE ONSHORE WINDSPEED AT 10M ABOVE GROUND LEVEL FOR STRATEGIC LOCATIONS ACROSS SOUTH-WEST NIGERIA 2000 – 2021													
LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
OBAFEMI OWODE	6.37	6.67	6.93	6.69	6.75	6.65	5.80	5.44	6.01	6.22	6.00	6.02	**6.29**
ABEOKUTA	1.99	2.19	2.34	2.34	2.18	2.35	2.75	2.90	2.34	1.93	1.64	1.72	**2.22**
ADO EKITI	2.17	2.22	2.34	2.40	2.16	2.24	2.50	2.60	2.02	1.70	1.61	1.89	**2.15**
IGBOHO	2.84	2.88	3.17	3.38	3.06	2.93	3.10	3.17	2.40	2.05	2.00	2.48	**2.79**
OKITIPUPA	1.06	1.08	1.03	0.96	0.90	0.98	1.10	1.16	1.01	0.88	0.82	0.91	**0.99**
SNAKE ISLAND	2.43	2.88	3.17	3.13	2.91	3.31	3.84	3.95	3.40	2.78	2.32	2.15	**3.02**
AKOKO	2.62	2.74	3.00	3.12	2.77	2.77	3.00	3.09	2.40	2.07	1.96	2.27	**2.65**
AKURE	2.17	2.22	2.34	2.40	2.16	2.24	2.50	2.60	2.02	1.70	1.61	1.89	**2.15**
IBADAN	1.99	2.19	2.34	2.34	2.18	2.35	2.75	2.90	2.34	1.93	1.64	1.72	**2.22**
IGBO ORA	2.27	2.42	2.59	2.64	2.46	2.58	2.96	3.09	2.41	2.01	1.74	1.96	**2.43**
IJERO EKITI	2.49	2.77	3.16	3.36	2.92	2.88	3.15	3.23	2.40	2.05	1.95	2.16	**2.71**
IKIRE	1.79	1.85	1.95	1.99	1.83	1.94	2.22	2.32	1.79	1.46	1.33	1.55	**1.83**
IKORODU	2.14	2.52	2.75	2.72	2.55	2.91	3.37	3.45	2.96	2.46	2.09	1.93	**2.65**
ILA ORANGUN	2.49	2.77	3.16	3.36	2.92	2.88	3.15	3.23	2.40	2.05	1.95	2.16	**2.71**
ILESHA	2.17	2.22	2.34	2.40	2.16	2.24	2.50	2.60	2.02	1.70	1.61	1.89	**2.15**
ISE EKITI	2.62	2.74	3.00	3.12	2.77	2.77	3.00	3.09	2.40	2.07	1.96	2.27	**2.65**
ISEYIN	2.27	2.42	2.59	2.64	2.46	2.58	2.96	3.09	2.41	2.01	1.74	1.96	**2.43**

ONDO TOWN	1.50	1.47	1.42	1.39	1.30	1.38	1.54	1.61	1.33	1.14	1.08	1.30	**1.37**
OSOGBO	1.79	1.85	1.95	1.99	1.83	1.94	2.22	2.32	1.79	1.46	1.33	1.55	**1.83**
OWO	2.17	2.15	2.19	2.23	2.06	2.15	2.41	2.50	2.00	1.69	1.57	1.87	**2.08**
SHAGAMU	1.79	1.93	2.03	2.06	1.94	2.10	2.46	2.58	2.10	1.72	1.46	1.55	**1.98**
LEKKI	2.14	2.52	2.75	2.72	2.55	2.91	3.37	3.45	2.96	2.46	2.09	1.93	**2.65**
MEAN	**2.33**	**2.49**	**2.66**	**2.70**	**2.49**	**2.59**	**2.85**	**2.92**	**2.40**	**2.07**	**1.89**	**2.05**	**2.45**

Table 5.2: 21-year monthly mean windspeed for the 23 stations at 10 m AMSL

LOCATION	10MASL MEAN	MEAN POWER (kW/m2)	COMMERCIAL THRESHOLD (kW/m2)
OBAFEMI OWODE	**6.29**	153.0478	26.36813
ABEOKUTA	**2.22**	6.728745	26.36813
ADO EKITI	**2.15**	6.112101	26.36813
IGBOHO	**2.79**	13.35635	26.36813
OKITIPUPA	**0.99**	0.596734	26.36813
SNAKE ISLAND	**3.02**	16.93932	26.36813
AKOKO	**2.65**	11.44492	26.36813
AKURE	**2.15**	6.112101	26.36813
IBADAN	**2.22**	6.728745	26.36813
IGBO ORA	**2.43**	8.824578	26.36813
IJERO EKITI	**2.71**	12.24004	26.36813
IKIRE	**1.83**	3.76902	26.36813
IKORODU	**2.65**	11.44492	26.36813
ILA ORANGUN	**2.71**	12.24004	26.36813
ILESHA	**2.15**	6.112101	26.36813
ISE EKITI	**2.65**	11.44492	26.36813
ISEYIN	**2.43**	8.824578	26.36813
ONDO TOWN	**1.37**	1.581382	26.36813
OSOGBO	**1.83**	3.76902	26.36813
OWO	**2.08**	5.534331	26.36813

SHAGAMU	**1.98**	4.773871	26.36813
LEKKI	**2.65**	11.44492	26.36813
MEAN	**2.45**	9.044267	26.36813

Figure 5.3: 21-year mean wind power potential for the 23 stations at 10mAMSL

MONTH	MEAN WINDSPPED (M/S)	MEAN POWER (kW/m2)	commercial threshold (kW/m2)
JAN	**2.33**	7.779342	26.36813
FEB	**2.49**	9.494523	26.36813
MAR	**2.66**	11.57497	26.36813
APR	**2.7**	12.10505	26.36813
MAY	**2.49**	9.494523	26.36813
JUN	**2.59**	10.685	26.36813
JUL	**2.85**	14.23671	26.36813
AUG	**2.92**	15.31171	26.36813
SEP	**2.4**	8.50176	26.36813
OCT	**2.07**	5.454892	26.36813
NOV	**1.89**	4.15203	26.36813
DEC	**2.05**	5.298302	26.36813
MEAN	**2.45**	9.044267	26.36813

Figure 5.4: 21-year mean monthly wind power potential for the 23 stations at 10mAMSL

Location	Windspeed (ms^{-2})	Power (kW/m2)	Commercial threshold (kW/m2)
OBAFEMI OWODE	7.18	227.6399	26.36813
ABEOKUTA	3.62	29.17433	26.36813
ADO EKITI	3.46	25.47437	26.36813
IGBOHO	4.21	45.89035	26.36813
OKITIPUPA	2.39	8.39593	26.36813
SNAKE ISLAND	4.06	41.1579	26.36813
AKOKO	4.04	40.55265	26.36813
AKURE	3.46	25.47437	26.36813
IBADAN	3.62	29.17433	26.36813

IGBO ORA	3.85	35.09597	26.36813
IJERO EKITI	4.06	41.1579	26.36813
IKIRE	3.24	20.91752	26.36813
IKORODU	3.69	30.8997	26.36813
ILA ORANGUN	4.06	41.1579	26.36813
ILESHA	3.46	25.47437	26.36813
ISE EKITI	4.04	40.55265	26.36813
ISEYIN	3.85	35.09597	26.36813
ONDO TOWN	2.68	11.83803	26.36813
OSOGBO	3.24	20.91752	26.36813
OWO	3.45	25.25413	26.36813
SHAGAMU	3.35	23.12116	26.36813
LEKKI	3.69	30.8997	26.36813
MEAN	3.76	32.69179	26.36813

Figure 5.5: 21-year mean wind power potential for the 23 stations at 50mAMSL

Month	Mean Windspeed (ms^{-2})	Mean Power (kW/m^2)	Commercial Threshold (kW/m2)
JAN	3.54	27.28255	26.36813
FEB	3.79	33.48056	26.36813
MAR	4.05	40.85453	26.36813
APR	4.11	42.69732	26.36813
MAY	3.83	34.55186	26.36813
JUN	4	39.36	26.36813
JUL	4.37	51.32387	26.36813
AUG	4.46	54.56067	26.36813
SEP	3.73	31.9155	26.36813
OCT	3.23	20.72443	26.36813
NOV	2.9	14.99924	26.36813
DEC	3.09	18.14473	26.36813
MEAN	3.76	32.69179	26.36813

Figure 5.6: 21-year mean monthly wind power potential for the 23 stations at 50mAMSL

For Onshore wind power, we are limiting the coastal environment for this study to the Bight of Benin of the Gulf of Guinea in the Atlantic Ocean for which the average windspeed stands at 4.91m/s mean representing a general

Tuijin Jishu/Journal of Propulsion Technology
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Vol. 47 No. 03 (2026)

wind class of 3 to 4 in the Beaufort Scale with higher values expected in the far ocean beyond the Bight of Benin within the Gulf of Guinea.

6.0. Discussion of Results

Wind energy potentials in Southwest Nigeria have over the years been blanketly adjudged by various researchers as generally not feasible for commercial-scale electricity production, which has by the results and tests of data using various viability analysis tools, proven to be mostly wrong. Although at 10m ASL, it appears only Obafemi Owode passes the 3.5m/s commercial windspeed threshold, but at 50m ASL, which is within the typical hub heights of commercial wind turbines, 75% of the 23 sites under investigation exceed threshold with average of 3.76m/s and ranging from 3.5m/s in Ilesha to 7.2m/s in Obafemi Owode. The mean wind speed and wind power variations across various months of the year are as shown in figure 4.1 and 4.2 based on 50m ASL

However, the windspeeds pattern in the region show great localization with hotspots variably distributed across zones such that even some locations with under 3.5m/s average windspeeds do have sublocations with above 3.5m/s. As such, there is need for the various stations to be atomized into large number of substations for finer data and more granular capture of specific districts within cities.

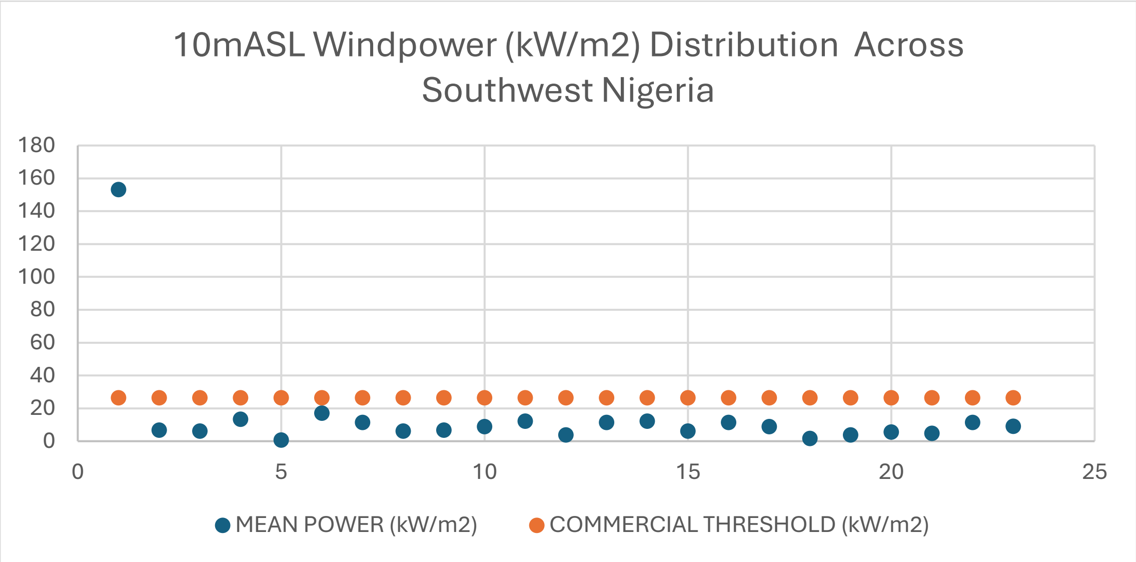

Figure 6.1: 10mASL Wind power distribution of Southwest Nigeria

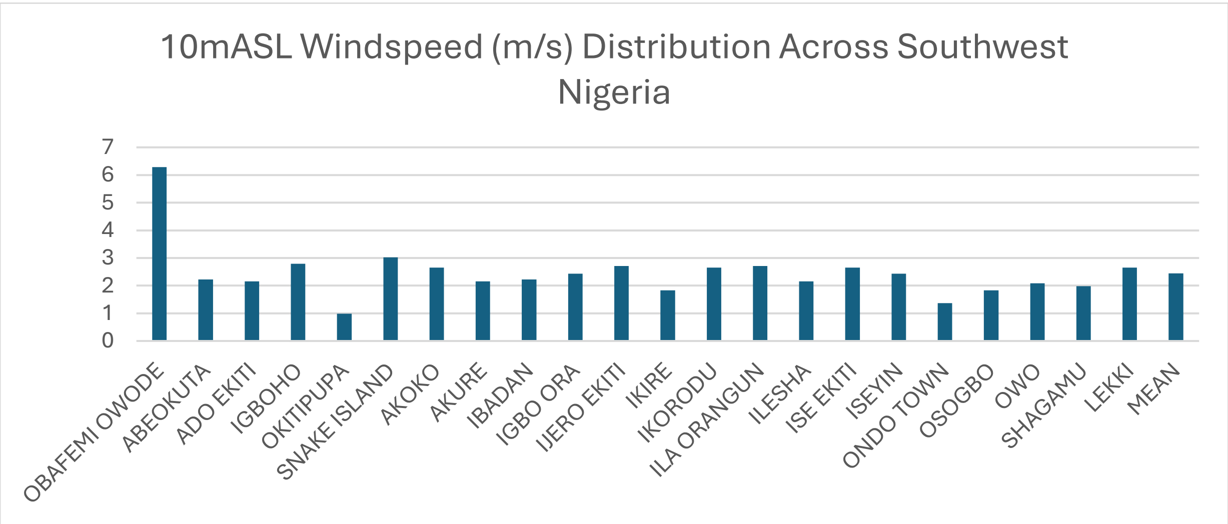

Fig. 6.2: 10mASL windspeed across Southwest Nigeria stations

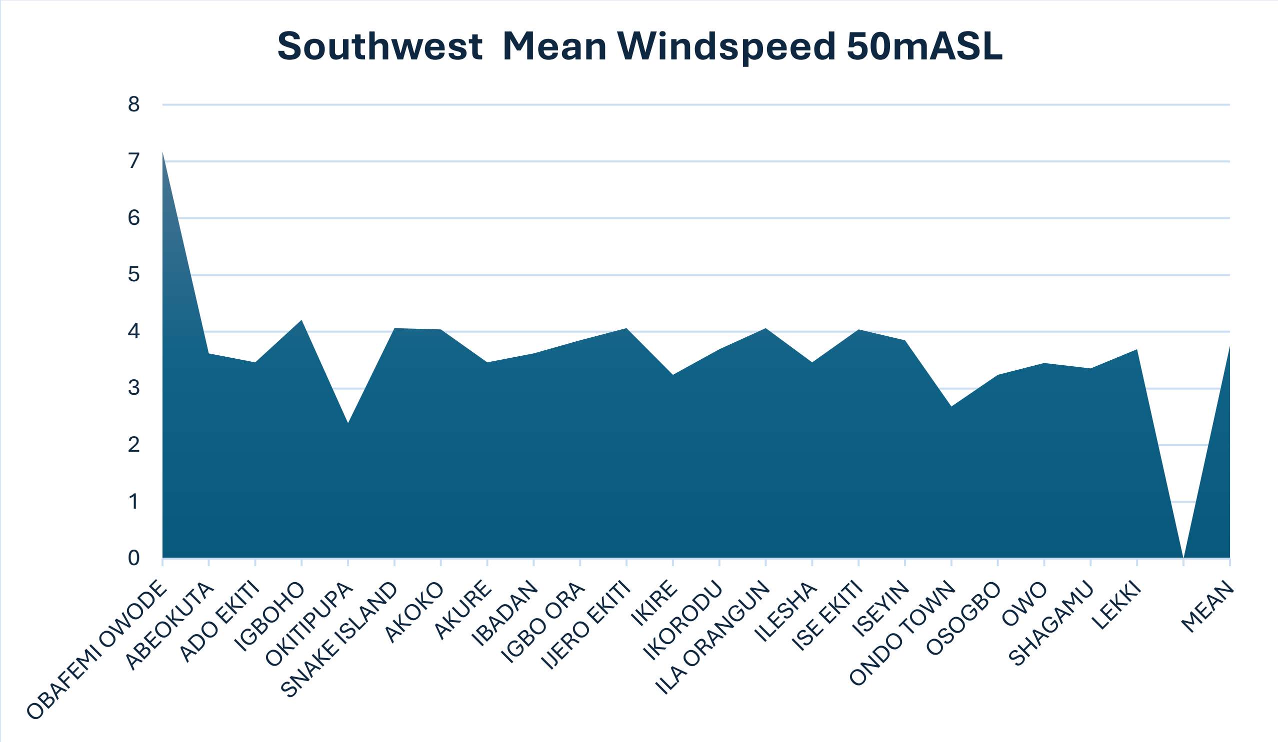

Fig. 6.3: Southwest Nigeria mean windspeed at 50mASL

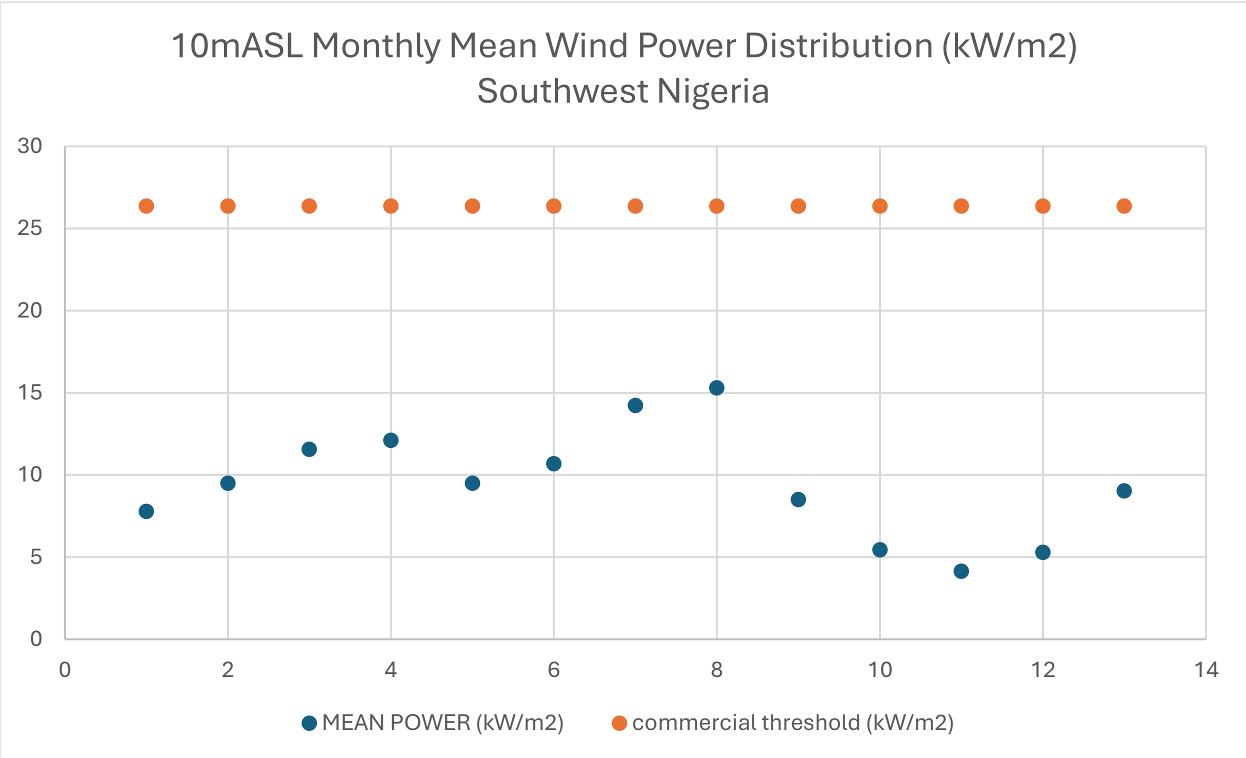

Fig. 6.4: 10mASL Southwest Nigeria wind power distribution

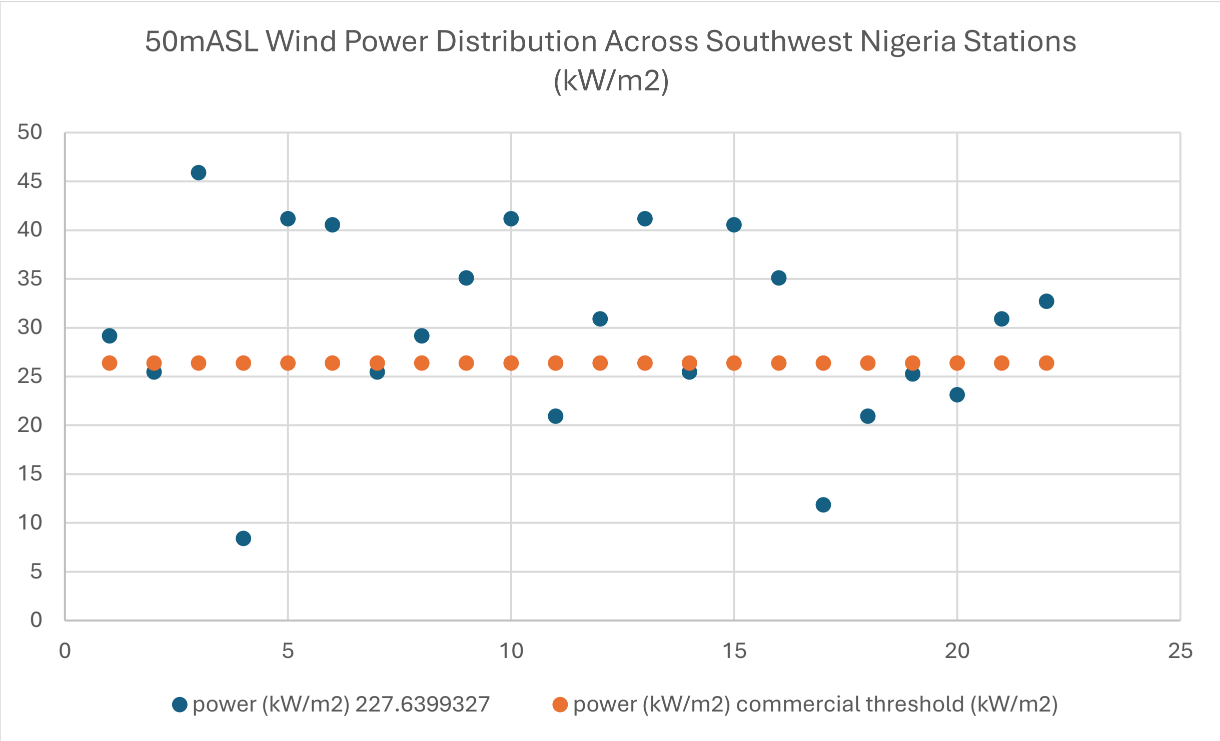

Fig. 6.5: 50mASL southwest Nigeria wind power regime

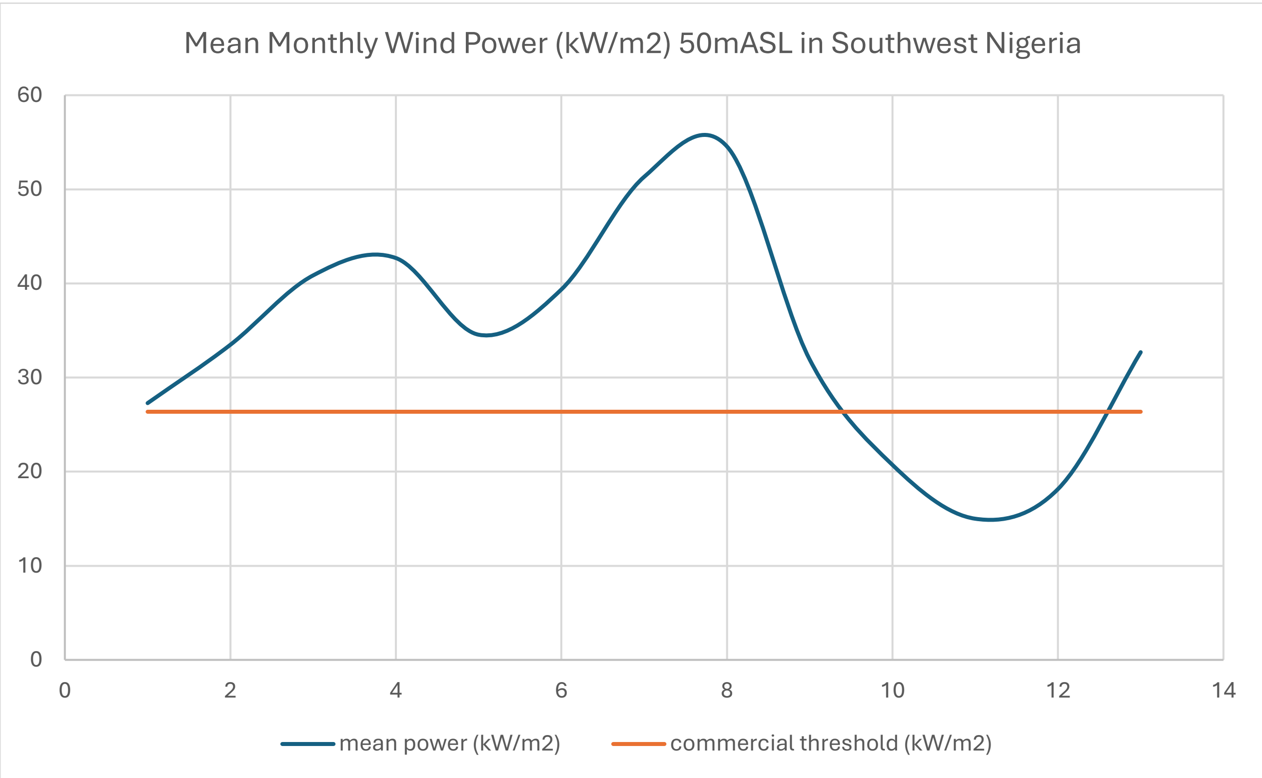

Fig 6.6: 50mASL wind power regime of Southwest Nigeria

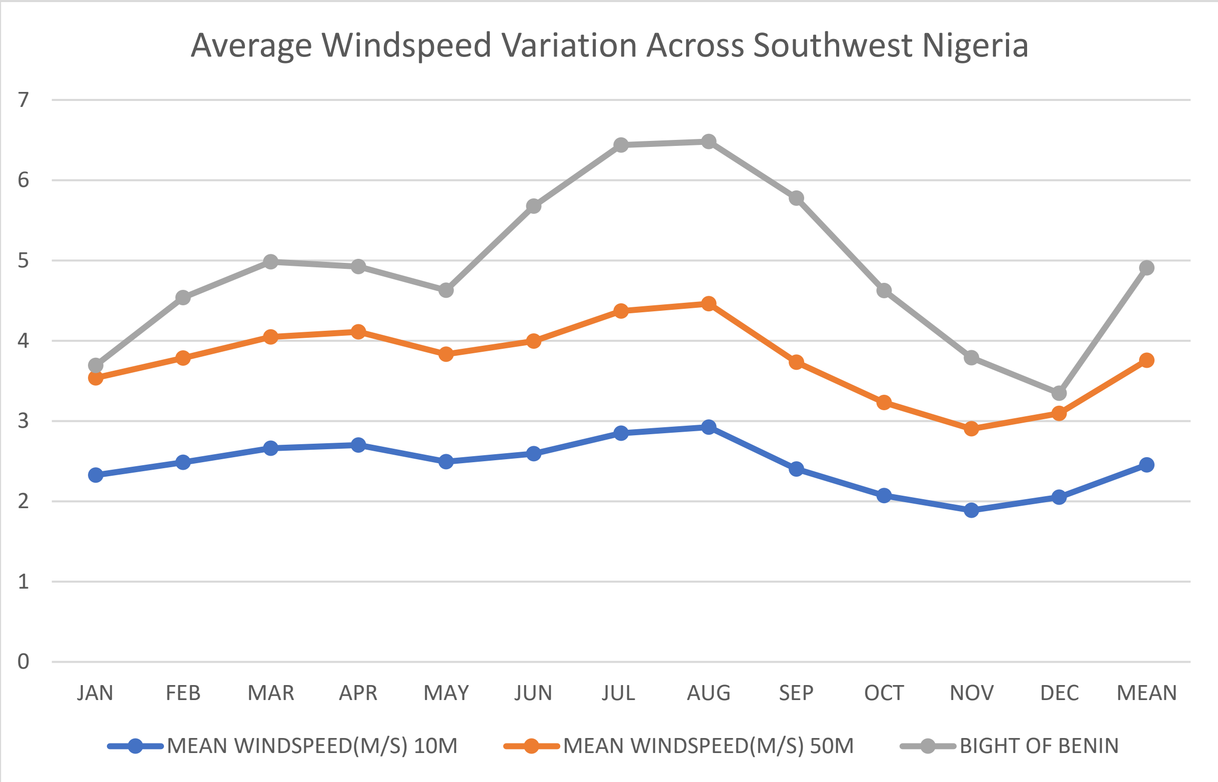

Fig. 6.7: monthly mean wind speed distribution at 10mAMSL and 50mAMSL

Having obtained handsome TEREVI, TELCOE, LCOE, and HOMER simulation results of 0.7028, $0.0265/KWH, $0.0249/KWH, and $0.0218/KWH, which show very conservative competitiveness compared to current rising energy prices, especially renewables, with further expected drop in prices with multiplication of capacities, onshore wind power focusing on the 75th percentile top viable locations as revealed in this study is commercially viable for electricity generation (Okwori et al, 2025). The TEREVI of onshore wind power in Southwest Nigeria is 0.702804, which is at the borderline of technical and commercial feasibility. The cost of energy is $0.013362281/kWh from HOMER optimization, $0.012298/kWh from Matlab simulation, $0.014077099/kWh from LCOE, and $0.014651/kWh from TELCOE with a mean COE from all energy model at $0.013597095/kWh which is very fair by all market standards locally and globally. Figures 6.1, 6.2, 6.3, 6.4, 6.5, and 6.7 show the wind speed and power potentials per square meter across southwest Nigeria and 10m and 50m hub heights based on results from various stations.

The prospect of land-based wind power generation is generally marginal in Southwest Nigeria, given mean windspeeds of 2.45m/s and 3.76m/s at altitudes of 10mASL and 50 m ASL, compared to the cut-in and commercial viability thresholds of 2.5m/s and 3.5m/s, respectively. This makes the windspeed in Southwest Nigeria to fall within Class 1 and Class 4 on the Beaufort Scale as shown in Table 4.43. Thus, the applicability of windspeed power generation is best at 50mASL and at locations of year–round high mean windspeed well above the commercial threshold. Hence, the mean wind power potential is 32.69kW/m2 at 50mASL and 9.04kW/m2 at 10mASL, while the commercial threshold is 26.37kW/m2.

At 10m hub height only Obafemi Owode is viable for wind power generation with average windspeed of 6.29m/s much above the 3.5m/s threshold while 14 of the 24 locations are found to have adequate mean windspeed suited for commercial power generation including Obafemi Owode (7.18m/s), Abeokuta (3.62m/s), Igboho (4.21m/s), Snake Island(4.06m/s), Akoko(4.04m/s), Ibadan(3.62m/s), Igbo Ora(3.85m/s), Ijero Ekiti (4.06m/s), Ikorodu(3.69m/s), Ila Orangun(4.06m/s), Ise Ekiti (4.04m/s), Iseyin (3.85m/s), and Lekki(3.69m/s) while Ado Ekiti, Ila Orangun, Owo, and Akure have marginal windspeed of 3.5m/s. Only 9 locations have windspeed above the 3.76m/s mean value, such as Ogbaho, Snake Island, Akoko, Igbo Ora, Ijero Ekiti, Ila Orangun, Ise Ekiti, and Iseyin, representing the best locations for siting a wind farm in Western Nigeria.

7.0. Conclusion and Recommendation

Wind power is a sustainable means of commercially viable, catenated or interoperable mini–grid electricity generation in specific locations in Southwest Nigeria, such as Obafemi Owode and other areas of high potential as highlighted in the results and analysis of this study, especially at 50m ASL or higher hub heights. Hence, with current hydra-head problems tied to inadequate power supply ubiquitous, it is exigent on government at all tiers especially with the recent abrogation of power from the exclusive legislative list to harness the high wind energy resources in Obafemi Owode and other high – prospect locations in Southwest Nigeria for power generation advisedly via interoperable mini-grids with necessary environmental and social impact assessment (ESIA) and mitigation carried out.

Due to deeply localized nature of wind energy potentials in the region owing to vast variations in topographies and physical developments as well as other wind speed influencing factors, there is a need for the establishment of meteorological and renewable energy data gathering stations evenly distributed across the region as ground confirmatory in pari passu with satellite recordings. In addition, the physical planning authorities must take into cognizance wind energy hotspots and create green zones in such areas in order to prevent the erection of obstructive structures and enable the ease of such land acquisition for wind farm projects for sustainable electric power generation in the short, medium, or long term.

8.0. Statements and Conflict of Interest Declarations

a. Conflict of Interest

The author has no relevant social, political, competing, or compromising affiliation to declare

b. Funding Statement

This research is fully self–funded by the author and therefore has no external sponsorship to declare

c. Financial Interest

The author has no immediate, short, medium, or long-term financial interest to declare with respect to this research

d. Employment

The authors of this research have no present, past, or future employment interest to declare with respect to this research

e. Social/Political Interest

The author of this paper has no past, present, or future political interest to declare with respect to this research

f. Authorship

I hereby declare that I, Christian Onuminya Okwori, is the only author of this research

g. Publication

This paper has never been published by another journal nor under consideration for publication elsewhere

h. Data Availability

The author is open to making available all relevant data from this study upon reasonable request

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