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Feasibility study for wind power generation in Langtang, Plateau State, Nigeria

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Abstract

This paper evaluates the prospect of siting a wind power generation system in the Langtang region of Plateau State in Nigeria. A review of the wind resources available in the region as well as current and projected energy needs is carried out to enable appropriate sizing of the power generation system.

To ensure there is market for the generated power, a review of current energy sources in use in the region and their associated cost is carried out. Economic analysis of the project is also conducted to ascertain profitability.

Detailed discussion on environmental issues associated with Wind Energy Projects is provided. This is because, despite the advantage of being a renewable energy system with the attendant environmental benefits, issues such as noise pollution, interruption of avian life migratory patterns, quality of power and unfavorable public perception are usually prevalent.

Finally, a review of public policy issues is done to provide a framework for regulatory guidance on the project.

Keywords: Feasibility Study; Wind Power; Wind Turbine; Capacity Factor; Hub Height; Payback Period; Environmental Impact Assessment

1. Introduction

Plateau is the twelfth-largest state in Nigeria, approximately in the center of the country.[1]

Langtang is a town in Plateau State located in the southern part with an area of 1,188 km^2 and a population of 140,643 at the 2006 census. The 2016 census projection indicated a population of 186,400 with an annual population growth rate of 2.7% [2]

The town has two dams and a water treatment plant that caters for its populace. They produce farm produce like groundnuts, millet, guinea corn, etc. [3].

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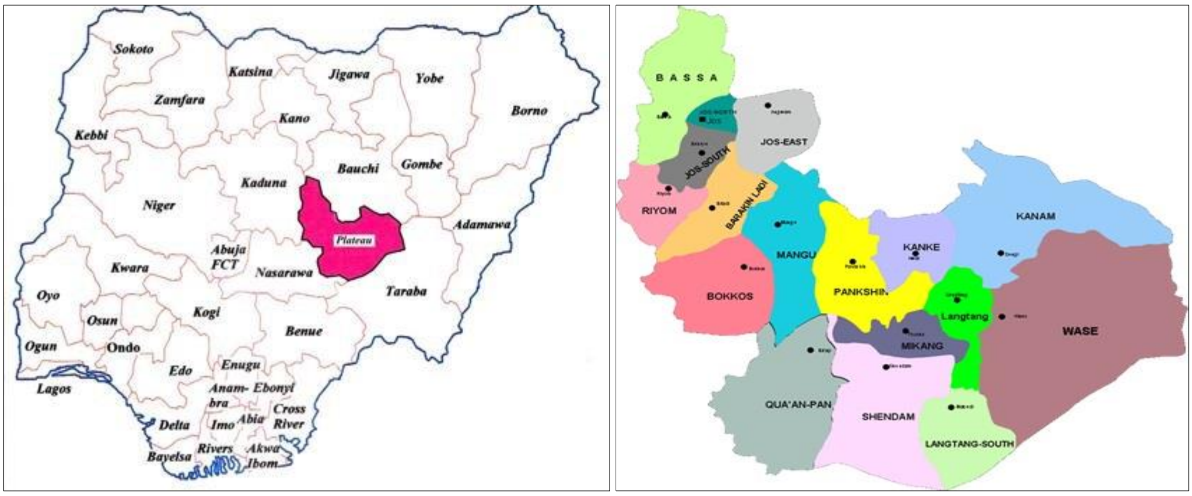

Figure 1 Map showing Plateau State and Langtang Town, Nigeria

There is not much documented information on the power consumption in Langtang. However, as of 2014, the electric power consumption in Nigeria was 145kWh per capita [4]. The Country currently has total installed and generating capacities of 12,522MW and 3,879MW respectively [5].

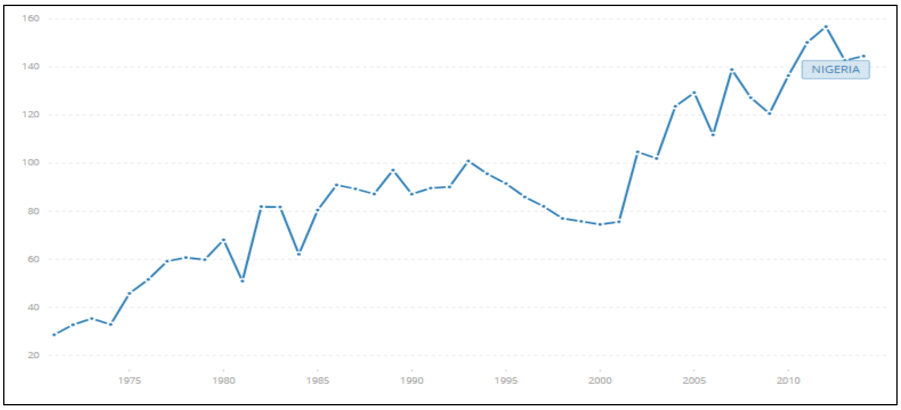

Figure 2 Electric Power Consumption in Nigeria. Source: World bank [4]

Based on world bank data of 2018, access to electricity in Nigeria currently stands at 56.5% [6]. This implies that a substantial number of households in the country are not connected to the National electric grid.

The population of Nigeria was 140,431,790 at the 2006 census with projected population of 193,392,517 in 2016 at an annual growth rate of 2.7% [2].

1.1. Energy needs of the region

The region under evaluation for siting of a wind power generation project is Langtang, Plateau, Nigeria with a population of 186,400 people based on the 2016 population projection. With a population growth rate of 2.7%, the energy needs of the region are sure to grow with increasing population over the next couple of years. Examining the current and projected energy needs of this region will allow for a more realistic analysis of a potential wind energy project.

Assuming a constant population growth rate, the population of Langtang will grow as shown in the table below:

Table 1 Projected Population Growth of Langtang

Year	2016	2020	2024	2028	2032	2036	2040
Projected Population	186,400	207,361	230,680	256,620	285,478	317,581	353,294

Data on the exact energy consumption of Langtang is not available. However, extrapolation shall be done based on available national data on per capita electricity consumption. This will provide a good approximation for sizing our power plant.

Using the data from World bank [4], if we consider the change in per capita electricity consumption for the 6-year period (2008 – 2014), we can estimate the increase in per capita consumption for 2020.

Table 2 Projected Energy Consumption in Langtang

Year	2008	2014	2020	2026	2032
Electricity Consumption (kWh per Capita)	127.245	144.525	164.152	186.444	211.763

In 2020, with an estimated population of 207,361, the per capita grid electricity consumption was about 164 kWh per year. We can then obtain as follows:

$$Annual\ Grid\ Electricity\ Consumption\ = 207{,}361\ \times 164 = 34\ \times 10^6\ kWh$$

$$Daily\ Grid\ Electricity\ Consumption = \frac{34\ \times 10^6}{365 \times 24} = 3{,}880\ kW \approx 4\ MW$$

The annual consumption of electricity per capita in Nigeria is amongst the lowest in Africa due to low generation capacity. Against this backdrop a significant number of homes and businesses operational in the country possess standby generators. [7]

A 2016 European Union Energy Initiative report on electricity demand in Nigeria provides data for a 25-year projection (2010 – 2035) [8]. From this report, the grid and off-grid electricity demand for Nigeria was projected at 165 TWh in 2020.

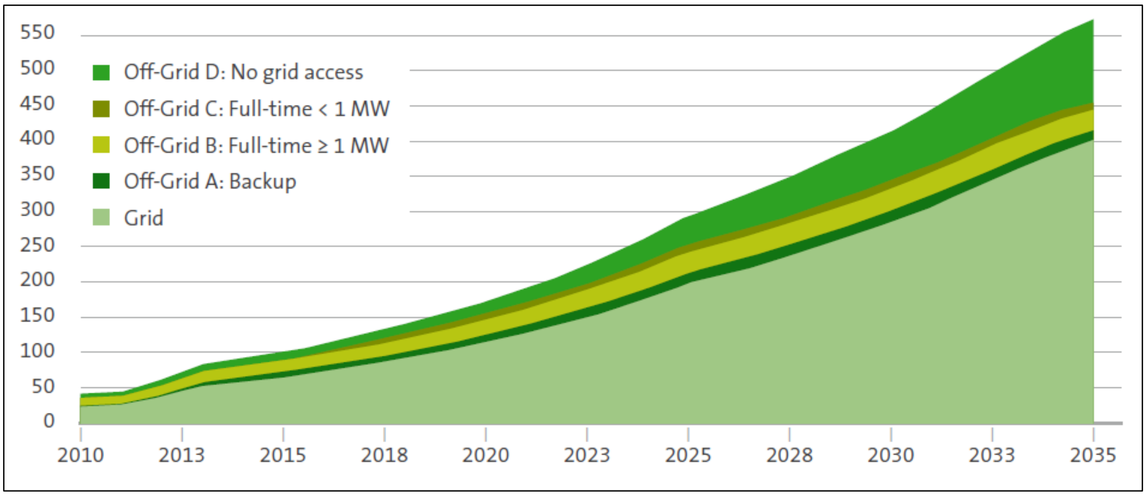

Figure 3 Projected Grid connected & Off-Grid Electricity Demand (Source: NESP, 2015b) [8]

The ratio of the population of Langtang to the entire country, assuming same population growth rate will be:

$$Population\ Ratio = \frac{186,400}{193,392,517} = 0.000964$$

The electricity demand in Langtang in 2020 can then be estimated as:

$$Electricity\ Demand = 0.000964\ \times 165TWh = 159 \times 10^6\ kWh$$

$$Daily\ Electricity\ Demand = \frac{159\ \times 10^6}{365 \times 24} = 18,150\ kW\ \approx 18\ MW$$

The electricity gap in Langtang is thus estimated as:

$$Electricity\ Gap = Daily\ Electricity\ Demand - Daily\ Grid\ Consumption$$

$$= 18 - 4 = 14\ MW$$

Based on the foregoing analysis, our wind power generation project aims to provide a healthy amount of steady electric power to Langtang.

Considering the current energy gap in the area, as well as projected increase in energy demand in the next few years, a 20 MW project is considered logical.

It is important to note potential inaccuracies with the above projection.

The electric power consumption per capita in Nigeria is an average of consumption in rural, suburban, and urban areas which does not accurately reflect on the consumption in the Langtang region.

The presence of large industries in the industrial hubs of Nigeria, Lagos, Port Harcourt, Kano etc. may skew the average energy figures.

The high altitude of Langtang and generally clement weather may also translate to less energy demand for cooling during hot periods.

2. Energy sources in the region

Specific data on Energy Sources for Langtang is not available because power generation and distribution in Nigeria is through a grid system and there are no installed power generation plants in Langtang. However, we can extrapolate using data for the entire country to provide good estimates for our feasibility studies.

Nigeria has about 12,500 MW of installed generation capacity from 25 generating plants, being largely dependent on hydropower and fossil (gas) thermal power sources; 15% and 85% respectively. Although it is important to note that currently only 3,500 MW to 5,000 MW is typically available for onward transmission to the final consumer [9].

Table 3 Installed Power Generation Capacity in Nigeria

Power source	Installed capacity
Hydroelectric	1,890
Thermal (gas)	10.632
Solar	-
Wind	-
TOTAL	12,500

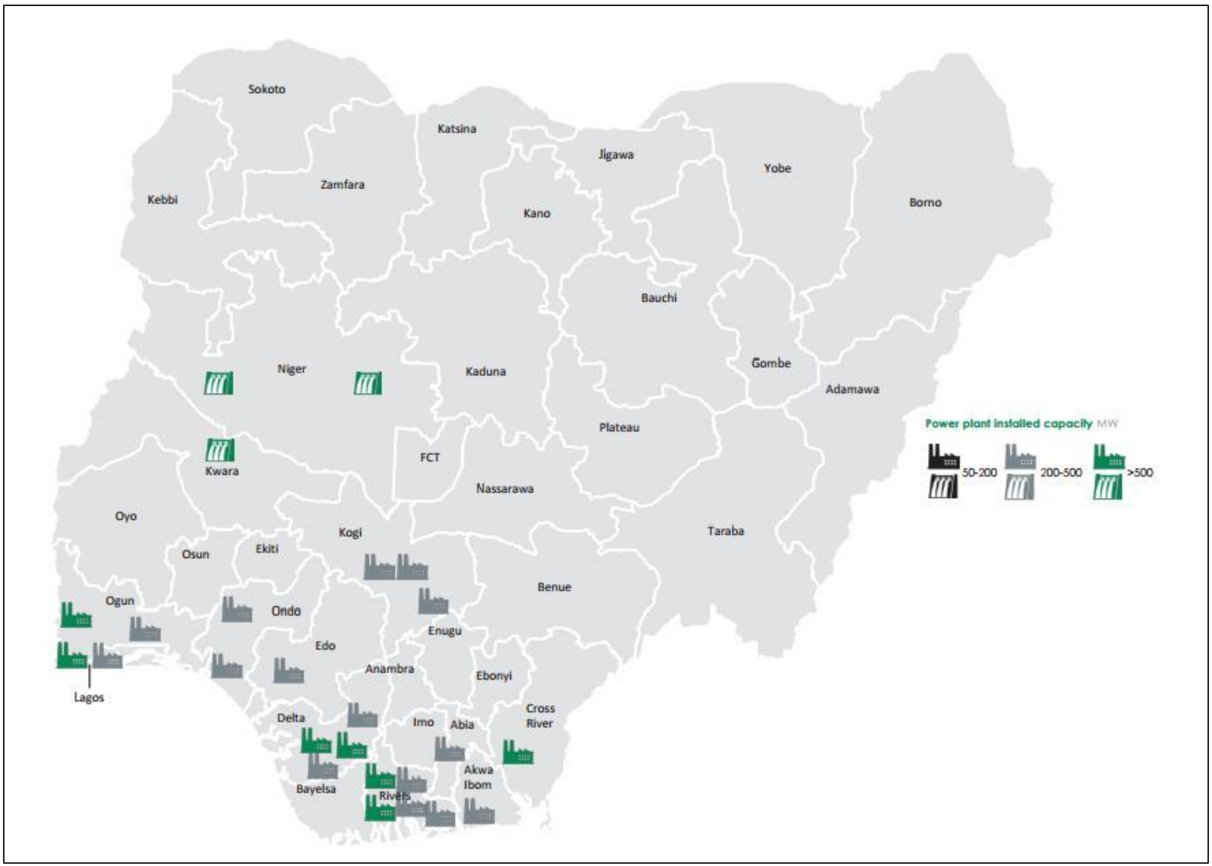

Figure 4 Distribution of thermal and hydro Power plants across Nigeria

The supplied electricity is delivered to Nigerians connected to the grid by the Distribution Companies (DisCos), though these customers suffer from extensive power outages, a situation that results in annual consumption of electricity per capita being amongst the lowest in Africa.

Against this backdrop a significant number of businesses operational in the country possess standby generators, statistics on this captive generation capacity are not readily available however estimates are as high as 14-20 GW [9].

The closest distribution company to Langtang is The Jos Distribution Company. Data on the cost of electricity from this company is obtained from the Nigerian Electricity Regulatory Commission (NERC) website [10].

Table 4 Electricity Prices in Nigeria

Electricity Prices	**Residential**	**Business**
Cost per kWh (Naira)	33.79	51.81
*Cost per kWh (US$)	0.09	0.14

*Currency Conversion is based on the Central Bank of Nigeria's (CBN) published exchange rate for 23/05/2021.

Considering that a substantial amount of energy currently available is via captive power generation, it is important to take the cost of off-grid power generation into consideration.

A 2017 report by the Nigerian Economic Summit Group and Heinrich Böll Stiftung Nigeria estimates the cost of captive diesel off-grid power generation in Nigeria at $0.45 per kWh. [11]

3. Wind resources availability

The map below obtained from the global wind atlas [12] shows the distribution of wind resources in Plateau State, Nigeria. The largest wind resources are available around the eastern part of the state with a large concentration in Langtang.

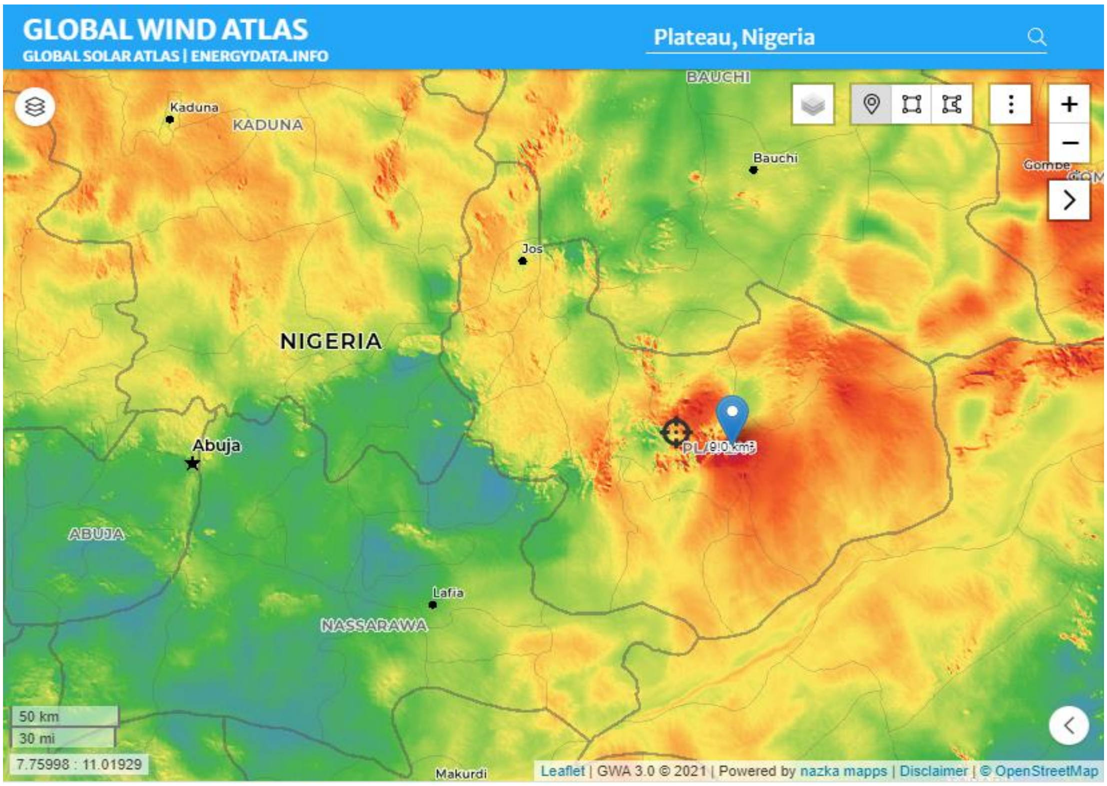

Figure 5 Wind resources in Plateau, Nigeria

Areas of the state where potential wind capacity factors exceed 35% at a hub height of 100 meters are indicated in the map [12] below.

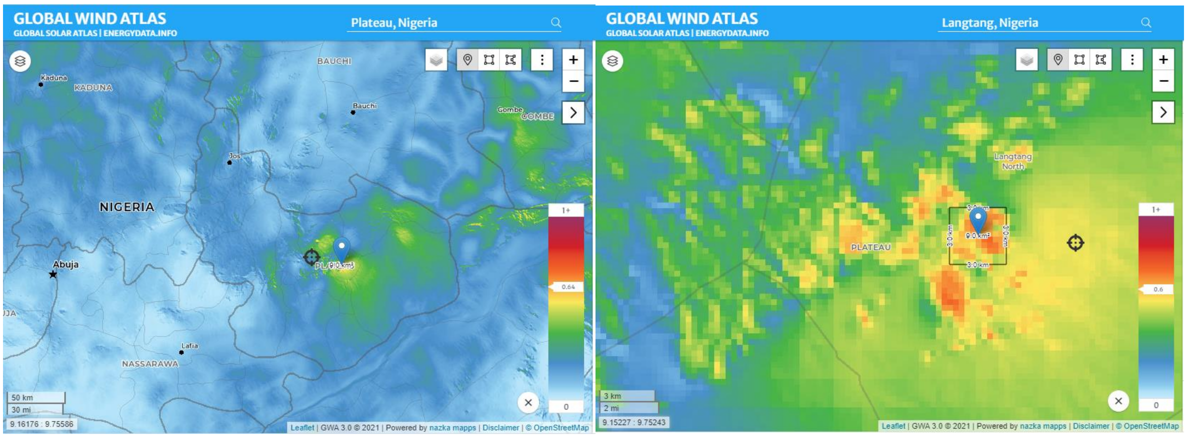

Figure 6 Capacity Factors for wind in Plateau, Nigeria

It is also seen that the highest capacity factors are available within the Langtang region and areas to the north-east of the state.

In the wind industry, 35% capacity factor is considered a benchmark for feasible wind energy generation [13].

By varying the hub heights from the global wind atlas, we observe that the wind resources around the Langtang region are significant.

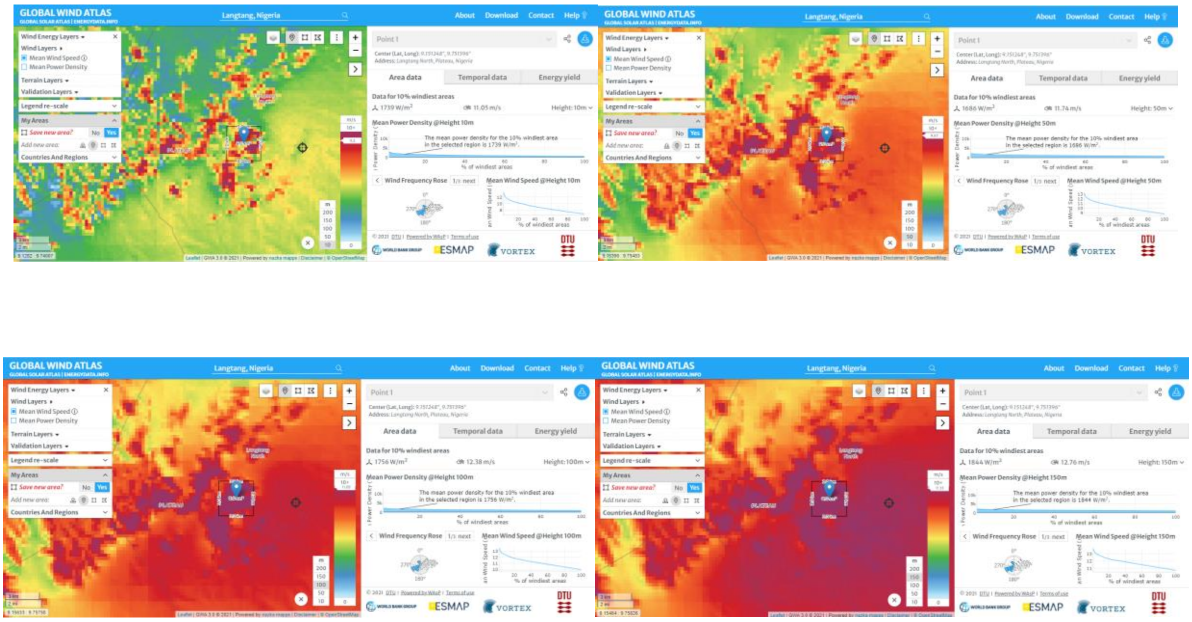

Figure 7 Wind resource data for Langtang at hub heights of 10m, 50m, 100m and 150m respectively

Table 5 Wind Resource Availability in Langtang

Hub Height (m)	**10**	**50**	**100**	**150**
Wind Speed (m/s)	11.05	11.74	12.38	12.76
Power Density (W/m^2)	1739	1686	1756	1844

A large amount of wind resource is available in Langtang with mean wind speeds reaching 12.76 m/s, mean power density of 1844 W/m2 and capacity factor of 0.6% at a height of 150m as obtained from the global wind atlas [12]

The urban population of Langtang is mostly concentrated in the northern and south-eastern parts. Significant regions of the south-west are mostly rural and thus can be used for a wind power generation project.

4. Wind power plant selection

Market research based on available offerings suggest two leading options to develop this project. The first option is General Electric's 1.7/103 Wind Turbine while the second is Vestas' V100-2.0MW IEC IIB turbine.

Considering that the Vestas option is more suited to be used in lower wind environments with a cut-in speed of 3 m/s and rated speed of 12 m/s, it offers to be a preferred option for this project [14].

A total of 10 units of 2 MW wind turbines will be required for the project, each installed at a hub height of 100 m. The units will be installed at minimum spacing of 250 m to provide sufficient room for installation and maintenance activities.

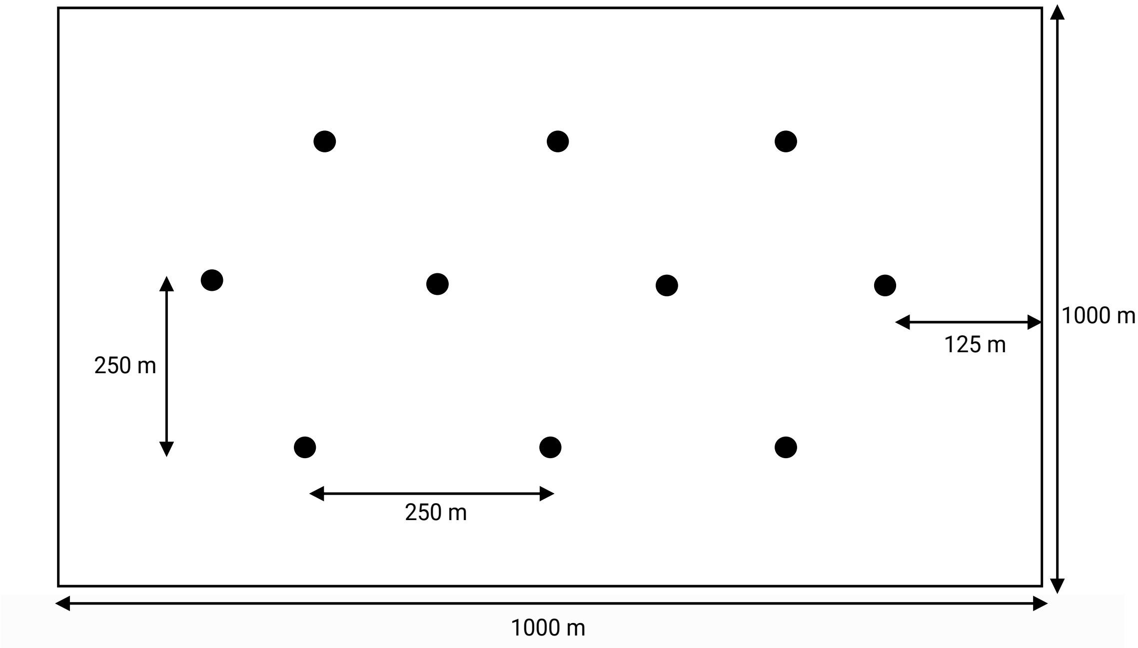

Figure 8 Proposed layout for wind farm

Considering the spacing requirements, a total land area of 1000m x 1000m (100 hectares) will be required for the wind farm.

The electric power generated will be sold to and fed into the nearby distribution network of the Jos Electricity Distribution Company. This will help minimize losses due to transmission over long distances.

Based on the current grid electricity availability in Langtang, the proposed wind power project will provide additional capacity to service the region. This will lead to a reduction in captive energy generation. This in turn will result in a reduction in air pollution with the attendant greenhouse effects.

The wind turbine project will also propel economic development in the region as more industries will be attracted towards the region. However, this will ultimately lead to increased energy demand.

5. Economic analysis

While no direct quotation for the cost of singular V100-2.0MW IEC IIB turbine was obtained from the Original Equipment Manufacturer (OEM), the general rule of thumb that 1 MW of wind power generation costs about $1.5 million is used to conduct economic analysis, assuming a 10% financial discount rate:

Size of Wind generation project = 20 MW

Cost per MW of Wind generation project = $1.5 Million

Discount rate = 10%

Cost of electricity (Residential) = $0.09/kWh

Cost of electricity (Commercial) = $0.14/kWh

$$Total\ Project\ cost = 20 \times 1.5 = \$30\ million$$

$$Cost\ of\ Energy = \frac{Total\ cost\ \times discount\ rate}{Capacity \times 24 \times 365 \times Capacity\ factor}$$

$$Cost\ of\ Energy = \frac{0.1\ \times 30 \times 10^6}{20{,}000 \times 24 \times 365 \times 0.6} = \$0.0285\ per\ kWh\ = 2.85\ cents\ per\ kWh$$

Assuming that most of the power will be sold to residential households in the region, then the wind energy generation cost will compete favorably with the current residential utility rates.

Considering the presence of a few commercial and industrial outfits within the region, we can assume an average pricing of 10 cents per kWh, as this will provide a reasonable estimate on revenues.

The profit per kWh of electricity will then be given as.

$$Profit\ per\ kWh = 10 - 2.85 = 7.15\ cents$$

It should be noted that this is a very generalized approach to the cost calculation that does not account for specific timing or local issues, exchange rates, competition, and contracting conditions. A more detailed assessment would be required to increase the accuracy of the projected cost per kWh.

The total expected annual profit will then be.

$$Annual\ projected\ profit = \frac{7.15}{100} \times 20{,}000 \times 24 \times 365 = \$12{,}526{,}800$$

Considering the initial capital invested in the project, the payback period of the project will be.

$$Payback\ period = \frac{30{,}000{,}000}{12{,}526{,}800} = 2.4\ years$$

Given the assumption that a proven turbine like the Vestas V100-2.0MW IEC IIB turbine would typically last for about 20 years, this project is expected to experience about 17 years of profitability assuming no major disruptions.

It is important to note that these estimations do not take taxation, inflation, rebates, renewable energy credits and maintenance costs into consideration. However, given the period of profitability it seems financially prudent to invest in this wind energy project.

6. Environmental issues

The effects of the entire energy infrastructure on the environment cannot be ignored for any wind power project. This is because, despite the advantage of being a renewable energy system with the attendant environmental benefits, issues such as noise pollution and interruption of avian life migratory patterns are usually prevalent.

The fear mostly expressed by environmentalists over the effects of the construction of a wind farm on flora and fauna life is mostly aggravated by lack of relevant information regarding the wind energy system. For this reason, it is critical to address any potential environmental concerns with all stakeholders and take measures to fully address their concerns prior to commencement of construction activities for any wind energy project.

6.1. Avian concerns

The location for siting of our Wind energy project is Langtang. The proposed site for the project is a developing area and not heavily populated. However, potential environmental concerns about bird migration through the area is important.

In the review of Migratory Bird Flyways conducted by the Convention on the Conservation of Migratory Species of Wild Animals (CMS/UNEP), five major flyway groupings are defined with Nigeria on the Black Sea/Mediterranean group [19].

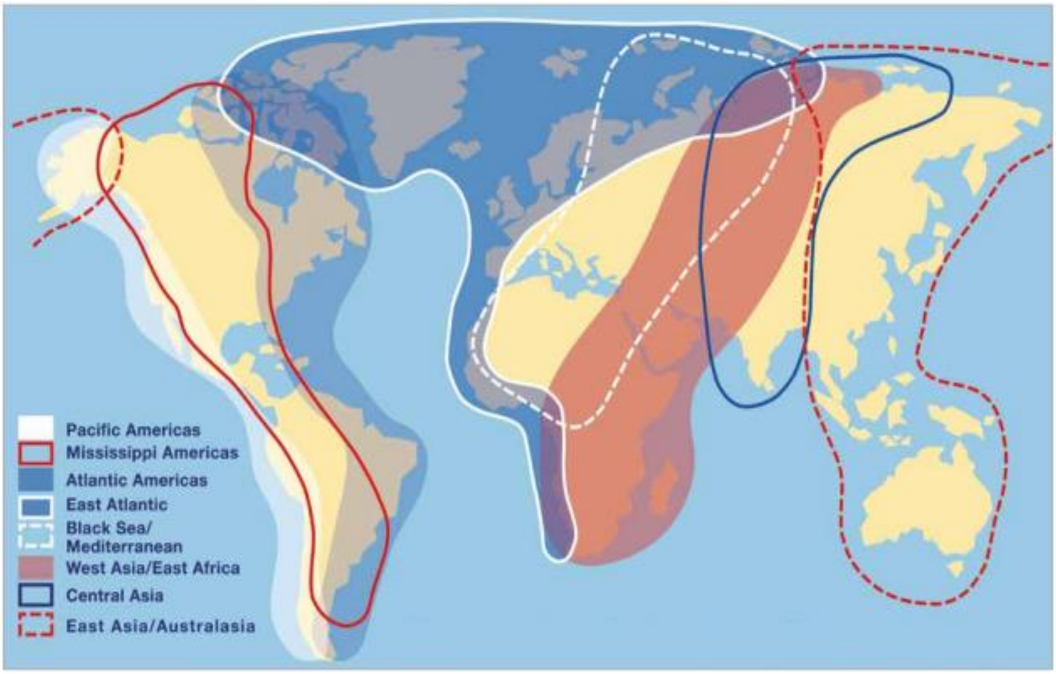

Figure 9 Major global flyways for migratory birds

Modern wind turbines are known to kill migrant birds by night or day, with losses estimated at a total of 33,000 birds per year in the United States in 2007 [19]. The greatest losses occur at wind farms situated on narrow migration routes or near wetlands, which attract large numbers of gulls and other large birds.

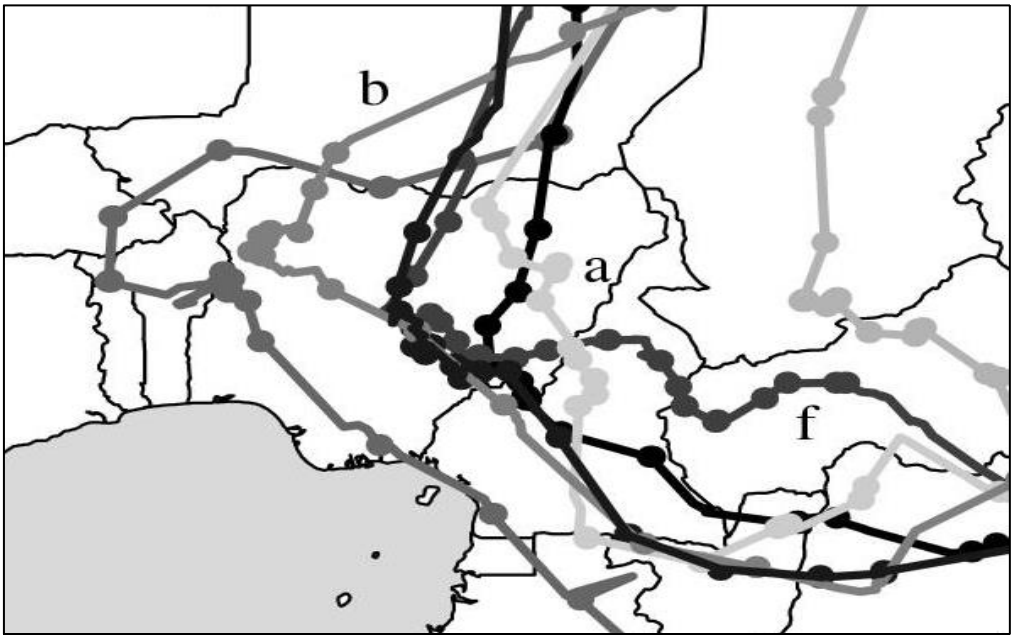

Figure 10 Migration path of seven juvenile Eleonora's falcons with stopover in West Africa

Analysis of the impact of windfarms on birds identified the main potential hazards as disturbance leading to displacement and exclusion, collision mortality, and loss of, or damage to, habitat [19].

Most studies have quoted low collision mortality rates per turbine, but in many cases, these are based only on bird corpses found, leading to under-recording of the actual number of collisions. Moreover, relatively high collision mortality rates have been recorded at several large, poorly sited windfarms in areas where concentrations of birds are present, especially migrating birds [19].

With increasing demand for wind energy sources, wind turbines could collectively begin to impose a more significant drain on migratory bird populations.

Research on the migratory patterns of birds across the west Africa region shows that two of seven juvenile species of Eleonora's Falcons migrate through the Langtang area [20] and could be impacted by this project.

The Nigerian Conservation Foundation (NCF), a partner of Birdlife International is passionate about preserving bird life and could provide further insight into the migratory patterns of birds through the region and an independent assessment of the effects of the wind energy project on avian life.

As part of efforts to address potential concerns from Stakeholders and environmentalists alike, the following steps shall be taken to address avian issues:

Contract the Nigerian Conservation Foundation (NCF) to carry-out a pre-construction assessment on the proposed location to identify potential impact of the project on avian life and make recommendations.

Have a representative from the NCF to make periodic visits to the project site, and constantly implement recommendations made throughout the project lifecycle. This will ensure that genuinely concerned environmentalists will have an individual through which they can channel their concerns.

Include strobe lights on the turbine blades to alert birds of their rotary motion.

Using a tubular structure for the tower of the turbine, rather than lattice, to minimize potential for bird perching.

Where it becomes almost impossible to prevent birds' invasion of the wind turbine site and consequent accidents, investment shall be made on a bird sanctuary close to the location. This will provide a safe haven and attract migrating birds intending to stopover, thus reducing the potential for invasion of the wind turbine site.

6.2. Noise

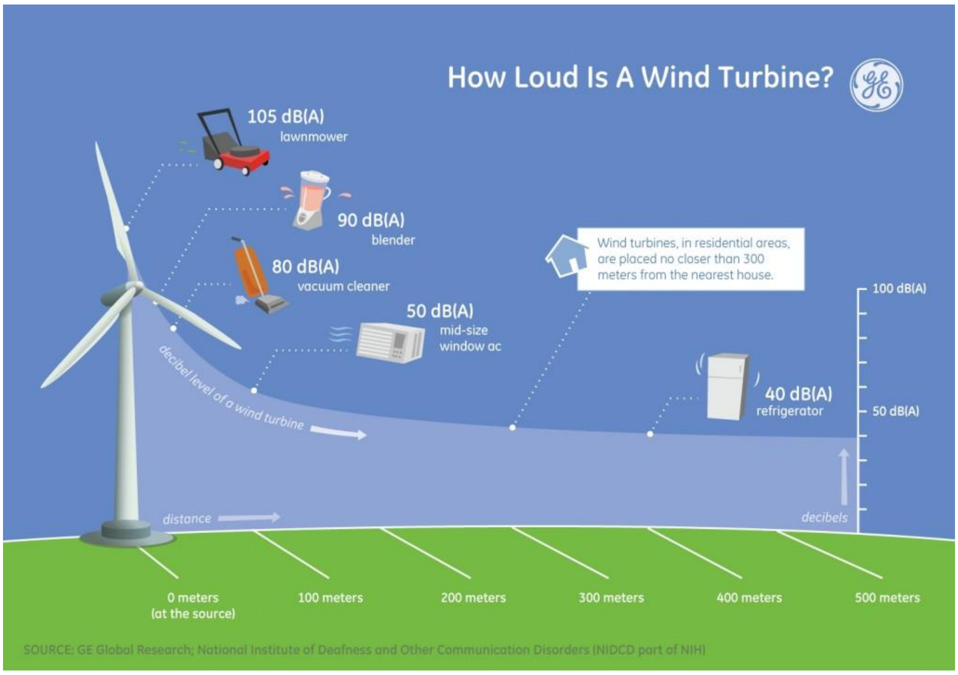

Figure 11 Comparison of the sound intensity of wind turbine to some common household appliances

Noise is a key issue to be addressed in the development of a wind energy project. An accurate and effective way to measure the level of sound of a system is using the IEC 61400-11 standards. Acoustic Engineers shall be engaged to implement these standards and provide accurate report on sound levels. The data obtained shall be used to ensure minimal noise effects on residential areas.

It is important to consider that noises from wind turbines in general are not extremely irritating in comparison to noises from gas turbine plants or large aircrafts take-off/landing. A comparison of the sound intensity of wind turbine to some common household appliances is provided below [21].

Considering that the proposed location is a rural area with low population density, the chosen site will be greater than 1 km from the nearest residential area, although, the exact location will be determined based on recommendations from the NCF to address avian issues as well as input from the community and other Stakeholders.

Siting a wind turbine farm sufficiently far away from residential areas can mitigate sound pollution. The energy dissipation from sound decreases logarithmically with distance, hence, for a 1 km distance, the sound effects of a wind turbine is negligible. Also, the collective sound effects from multiple turbines does not increase significantly with the number of units [22].

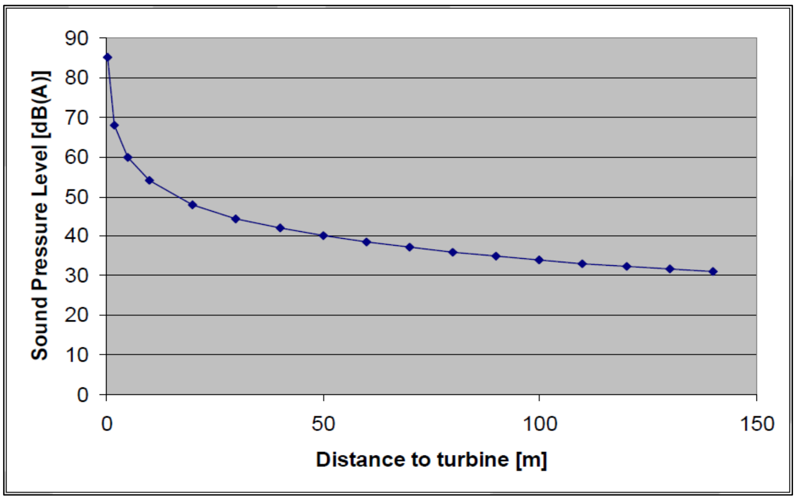

Figure 12 Variation of sound intensity with distance

Although, siting the wind turbine farm sufficiently far away from residential areas can mitigate potential noise pollution, it is important to consider future population growth and residential area expansion towards the wind turbine site. To address this, further analysis shall be conducted on each turbine component to minimize their noise level.

Much of the noise from a wind turbine is as a result of the blade moving through air. This is due to the boundary layer of air formed along the turbine blade. Serrating the trailing edges of the blades can help reduce this level of noise.

Similar independent analysis of noise emanating from other components of the turbine system such as the cooling fans, generator, power converter, hydraulic pumps, yaw motors, bearings, and blades etc. and implementing counter measures can help reduce the overall noise from the system.

6.3. Power quality

Wind power plants must provide the power quality required to ensure the stability and reliability of the power system it is connected to and to satisfy the customers connected to the same grid.

To ensure that this is achieved, power quality Engineers shall be engaged to carry out analysis of the proposed Wind power generation system vis-à-vis the existing power transmission grid and make recommendations to ensure power stability.

It is important to understand the sources of disturbances that affect the quality of power. These include voltage and frequency fluctuations, current distortions created by harmonics, flickers, faults, start-up transients etc. It is desirable to keep the voltage and frequency stable as much as possible.

Because the loads and the wind power plants' output fluctuate during the day, the use of reactive power compensation is ideal for maintaining normal voltage levels in the power system network. Reactive power compensation can minimize reactive power imbalances that can affect the surrounding power system [23].

Frequency variation is affected by the rate of change in real power flow. Thus, there is a difference in the trend between the voltage-reactive power traces compared to frequency-real power traces relationship. The reactive power improves the voltage characteristic of the wind power plant and surrounding area.

In general, the voltage at each turbine within the wind power plant varies independently because of the difference in wind speeds, the line impedances, and compensations among the wind turbines. However, a reactive power compensation, strategically placed, affects the voltage behavior of a very large area consisting of many wind turbines [23].

6.4. Public acceptance

The urban population of Langtang is mostly concentrated in the northern and south-eastern parts. Significant regions of the south-west are mostly rural and thus can be used for a wind power generation project.

Residents of Langtang, and Nigeria in general, suffer from extensive power outages, a situation that results in annual consumption of electricity per capita being amongst the lowest in Africa [7]. As a result of the current power challenges being experienced, the residents of Langtang appear to be very open to new investments in wind energy projects.

In addition, public hearings regarding the wind power generation project will be held in the community town hall to address any concerns that residents may have and to intimate them on the measures already being taken to avoid inconveniences to the populace.

7. Public policy issues

The following public policy issues may directly or indirectly affect the development of our wind power generation project:

7.1. Incentives

The National Renewable Energy and Energy Efficiency Policy (NREEEP) [17] provides incentives centered around renewable energy, some of which include:

- Customs duty exemptions for two years on the importation of equipment and materials used in renewable energy projects.
- Five-year tax holidays for manufacturers from date of commencement of manufacturing.
- Five-year tax holidays on dividend incomes from investments in domestic renewable energy sources
- Provision of soft loans and special low-interest loans from the power sector development fund for renewable energy supply.
- Grants to communities to encourage renewable energy projects.

There are currently no tax credits for renewable energy as the Nigerian market has yet to develop sufficiently to accommodate initiatives of this kind; however, there are plans by the federal government, under the NREEEP, to introduce tax credits for producers of renewable energy appliances and fixtures.

The proposed 20 MW Wind power generation project is expected to benefit from the customs duty exemptions and tax holidays as most of the equipment for the project will be imported. Access to low interest loan from the Government also looks attractive.

7.2. Renewable energy credits

Nigeria's renewable energy market is still largely new and not sophisticated enough to ascribe special values to electricity from renewable energy in terms of green attributes or renewable energy credits. However, it is important to note that NREEEP proposes a power production tax credit (PPTC).

The PPTC seeks to incentivize individuals who generate electricity from renewable energy with tax credits. While this has not yet been implemented in Nigeria, it is a step in the right direction towards improving Nigeria's energy mix, as well as placing value on electricity generated from renewable energy. It is expected that the implementation of the policy and the PPTC will encourage private investment in the industry.

The proposed 20 MW Wind power generation project will benefit from the power production tax credit if/when implemented.

7.3. Licensing

- The Nigerian Electricity Regulatory Commission (NERC) issues licenses to entities that wish to engage in the business of generation, transmission, and distribution of electricity [15].
- In addition, the Commission issues Permits for Captive generation, i.e., electricity generated for consumption by the generating entity and not sold to a third party.
- The Commission licensing purview does not include entities that generate 1 MW and below of electricity or a distribution network of 100KW or below.
- The proposed 20 MW Wind power generation project intended for Langtang falls under the purview of NERC and will thus require licensing.
- The guidelines for the installation of masts and towers require that towers above 25 meters in height would not be permitted within districts delineated as residential. [16]
- A minimum distance of mast height plus 25m is also required between the mast and any adjacent building.
- Masts above 150m height requires special permissions.

7.4. Environmental impact assessment

To ease the cost implications and steep timelines associated with Environmental Impact Assessments (EIAs), the EIA Guidelines provide that projects under Category II (which includes any renewable energy development) that are not located in an environmentally sensitive area may not be mandatorily required to undertake a full-scale EIA but will be required to undertake a partial EIA.

The Langtang Wind power generation project will not require extensive EIA based on the site selected.

8. Conclusion

The proposed 20 MW Wind power generation project under consideration shows promising economic and performance results. The location offers high wind speeds, a desirable capacity factor, and minimal disturbance to residential areas.

This wind project has the potential to offer clean energy for a price comparable and even lower than the average cost of electricity in the region. The project economics suggests project viability with a payback period of about 3 years, excluding cost of operations and maintenance.

A thorough examination of the environmental issues shows noise pollution, interruption of avian life migratory patterns, quality of power and unfavorable public perception may not pose serious challenges. Also, there are currently no public policies against development of Wind Power Projects in the region, rather, there are several potential cost-reducing policies planned for implementation.

Based on the foregoing, the Langtang Wind Energy Project appears feasible and expected to provide a healthy amount of energy to the region at a competitive rate.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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