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Assessing the Technical Offshore Wind Energy Potential in Lagos, Nigeria

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Abstract. Looking at the current state of things globally and the greenhouse effect renewable energy sources are no longer a matter of choice. The population of Lagos coupled with the perpetually erratic power supply makes renewable energy the new and sure way to go especially as an alternative supply of electricity. The nation as a whole has a peak generation of 5300MW on average which is only about 30% of its actual needs. The use of renewable energy in Nigeria is growing but so is the population this study seeks to ascertain the possibility of using offshore wind energy as an alternative power supply in Lagos Nigeria. The onshore wind energy resource has been fairly explored but its counterpart offshore wind energy has not been explored. This study focuses on the technical assessment of offshore wind resources on the Gulf of Guinea around the Lagos Nigeria region. Having analysed wind data from existing literature and analysed offshore wind farm construction the paper presents a technical layout of the number of turbines per the specified area and the potential output using Aerodyn SCD 8.0/168 as a case study. The results show that the annual energy demand of about 96.36TWh in Lagos can be met with the annual generation of about 191.2TWh for a wind farm at the shore and 200TWh for waters with depth less than 50m.

Keywords: Offshore, Energy, Wind Energy, Lagos.

1. Introduction

Nigeria as a country has been experiencing a constant reduction in her energy sector with over 50% of its 190.9 million people having no access to power supply[1]. This population is estimated to increase to 263 million by 2030 with more Fossil fuel consumption and dependence. This is fast becoming unrealistic and dangerous as over 80% of electricity and 23% of cooking plus transportation and production are dependent on fossil fuel[2]. The country is Africa's largest consumer of oil-fired stand-by generators as a back-up supply of electricity inspite of its large renewable energy potentials[2]. According to the International Energy Agency (IEA) the energy supplied would need to be more than four times its current amount to be sufficient for the populace [2].

In order to satisfy the requirement of the 7th Sustainable Development Goal (SDG), there is need for not just an increase in the energy supply of the state but also an increase in the inclusion of carbon emission free electricity supply. To have a reduction in carbon emission electricity supply, we will need to access the available renewable energy around us such as wind, piezoelectric, geothermal, solar energy sources for use as either alternatives, substitutes or additions to existing sources for meeting all forms of energy demands[3]. Wind speed as a source to generate electricity is gaining ground all over the globe quite recently due to its fast advancements in technology. These advancements in technology have made offshore wind energy not just a reality but a superior alternative to onshore wind energy harvesting inspite of its initial high installation cost[4]. Offshore



wind energy harvesting is the only sure way to large scale wind farming due to the onshore wind energy harvesting limitations such as visual and noise pollution and unavailability of sufficient area for the installation of turbines[5].

Northern states like Jos, Katsina and Maiduguri, have high onshore average wind speed of 5.32 m/s obtained at height 10m above the ground surface but not as much as can be harnessed offshore in the southern coastal regions in Nigeria [6]–[8]. The coastal wind speed distributions show that offshore wind energy conversion at the southwest region of Nigeria is very viable. More than 90% of the offshore wind resources are concentrated in coastal zones associated to three African Power Pools [9]–[12]. Research has shown that there is a higher offshore wind energy potential in southern Nigeria than onshore in northern Nigeria[6], [7].

Lagos state as the nation's centre for excellence is a hub for business, with a population of 20 million people as at 2016[13]. An Energy demand analysis carried out by the Lagos State Government estimated the total demand of electricity as 10GW as of 2011 and increased to 11GW as of 2015, with 70% of this for residential use [2]. The energy supply in the state leaves its residents with between 1 to 5 hours of electricity daily which gives us picture of the gap between demand and supply[13]. Majority of the nation's businesses and companies are resident in Lagos and spend so much money on individual standby generators to keep the businesses running[2].

One major advantage that offshore wind energy will have over onshore wind energy harvesting in a place like Lagos state is a reduction in the impact on its environment. Lagos state is a very populated state hence the construction of an onshore wind farm is almost impossible because of the environment. Also a sufficiently large wind farm is only possible offshore[4], [9], [14]. This paper will assess the technical offshore wind energy potential for use in Lagos. This feasibility study was done at a hub height of 135m in the coastal region of Lagos, Nigeria for use as an alternative or addition to the supply of electricity in Lagos .

2. Theoretical Background

To effectively assess the offshore wind energy potential there are some other potentials we need to know and understand to have a holistic view of how much energy can be harnessed. The entire wind energy that can be harnessed depends on the following factors; market, economic, technical and physical or topographical factors[9][12]. The most important of these factors are the physical or topographic factors. The wind energy available in a location is the predominant physical or topographic factor and it depends on the wind speed, wind direction and the consistency in the wind flow.

The total electricity that can be harnessed from a turbine to a large extent is determined by the wind speed available in the area it is mounted among other factors. The technical factors are the actual performance of the individual turbines, the wind farm performance, other users on the water body and its effect of the performance[15]. The factors can be classified based on the turbine locations: shallow water or deep waters. They depend on the physical or topographic factors. The technical factors will give direct information on how much electricity can be generated from the wind farm. Economic factors which are springing from the technical factors will deal with the cost implications of the entire structure and how readily available the technology is, which will involve clearance fees, taxes, cost of equipment etc[16]–[19]. Lastly the cost implications will have to be handled by investors, this is an analysis of how this will sell in the market which is the supply-demand factors[16]–[19]. This paper focuses on the technical factors as it aims at providing information on how much electricity can be generated from offshore wind energy available in the southern coastal region Lagos state, Nigeria.

2.1. Wind Speed:

This is paramount in wind energy harvesting as the energy harvested is dependent on it. The output wind energy in watts is given by the equation below[20], [21]:

$$P = 0.5 \times \rho \times A \times v^3 \times C_p \text{ (in watts) } \dots \dots \dots (1)$$

Where v is wind speed, A is the area swept by the rotor blades,
ρ is the air density, *C_p* is the power coefficient

The wind supplied to the turbine can either be above the cut-out speed or below the cut-in speed. When the wind exceeds the cut-in and cut-out wind speed boundaries the turbine will not operate. The average speed distributions for the coastal regions in Nigeria, of which the coast around Lagos is one, is 5.28m/s at a height of 10m which is taken as the wind speed at shore which is far less than the wind speed that will be obtained offshore [22]. This wind speed is within the turbine’s acceptable speed limits as we will see in the next section. A comparison between the wind speeds at the shore closest to the water body and the wind speed at close to shore with a depth of below 50m and the wind speed over deep waters is shown in Table. 1[9], [15], [23].

2.2 Turbine Performance

Dealing with the nature of resource the turbine uses and its uncertainties, capacity factor is a major yardstick for measuring performance. Capacity factor (CF) refers to a unit-less ratio of output over a period to maximum possible output of electrical energy[9]. In this paper the reference turbine used was Aerodyn SCD deep float 8.0/168. This turbine allows for a single mount including the tower and foundation. Also this turbine due to its two blade system has less resistance to wind and is most effective for areas that are not so spacious. The chosen site-specific height above sea level proposed is 135m, the blade diameter is 168m and rated capacity is 8MW given its rated wind speed. The cut-in speed for the selected turbine is 3.5m/s and its cut-out speed is 25m/s[24]. The relationship between wind speed and capacity factors was also analysed and the results showed that the CF gets better with an increase in average wind speed [9][25][26].

2.3 Wind Farm Performance

The wind farm performance depends largely on the individual performance of the turbines but not entirely. The wind farm performance has a combination of factors; foundation and tower, blade system, generator, electrical and electronic components, power train [27][28]. The proposed foundation is the jacket foundation with a floating structure to allow for depths beyond 60m[29]. The blade system used in the proposed turbine is a two-blade downwind system this will allow for the proposed jacket foundation with less need for tower clearance in the case of counteracting loads. This will allow more turbines in less space.

2.4 Cost

With the advancement in technology we are able to harness more energy with less cost. This includes installation time; the same installation time yields more energy due technological advancements[30], [31]. The focus of this study is on the technical potential of offshore wind energy hence the analysis of the economic and market factors are not within the scope of this paper.

Table 1: Showing a Comparison between the three water levels[9], [15], [23]

Factors	At the Shore	On the water (less than 50metres)	50 meters and beyond
Wind Speed	Low	High	Very high
Turbine performance	Low	Fluctuating	More stable and

Wind performance	farm	Unstable	Average yield	efficient More yield
Other users of the water body	of	Mostly disturbed by port users	Less disturbance	Very minimal disturbance
Availability technology		Readily available	Readily available	Less readily available
Cost		Expensive	Expensive	More Expensive

3. Methodology

The focus of this study is at the coastal region of Nigeria due to its proximity to the Atlantic Ocean located between latitude 4°N-8°N. The methodology adopted for the study follows the following step[5]

- Bathymetry data, exclusive economy zone
- Potential area for powergeneration.
- Calculation of the turbines numbers needed.
- Wind data atdesired hubheight.
- Output Power.
- Potential annual energy generation

3.1 Bathymetry data and exclusive economy zone

The topography(bathymetry) of the ocean is a major component in this assessment as it determines how much we can get from the wind farm and how what type of turbine technology to use particularly the foundation [5]. The varying depths of the sea is determining factor for the net output as shown in table 1. Most efficient wind farms are those located at depths beyond 50m. The bathymetry data was retrieved from GEBCO (General Bathymetry Chart of the Oceans). Lagos has no official records of zones reserved for commercial fishing and other port activities but most of the import and export that occurs via water happens through the Lagos port as it is a major port in Nigeria. The depths of the turbine used for this study is 50m but with a floating foundation technology it can be planted in deeper waters [32]. For depths like this we expect less confinements and more available area towards the southern part of the Nigerian political jurisdiction of the Atlantic. The topographical impacts on this project will also have to be ascertained during construction [33], [34].

3.2 Calculation of offshore wind potential

3.2.1 Wind data analysis

The wind data in term of speed was the bedrock of this study as the wind energy and wind density powers is speed dependent. A thorough analysis of the speed was done for coastal regions in Nigeria of which Ikeja Lagos is one[10][32]. A wind speed of about 8.79m/s was obtained after scaling it to the turbine’s hub height using the log law formula shown in equation 1. Given $Z_o = 0.2mm$ [5], [35], [36]

$$v(Z) = v_{ref} \frac{\ln\left(\frac{Z}{Z_o}\right)}{\ln\left(\frac{Z_{ref}}{Z_o}\right)} \dots \dots \dots (2)$$

Where $v(Z)$ is the wind speed at hub height, v_{ref} is wind speed at the height Z_{ref} .

The presence of varying air pressure in the coastal regions of Nigeria show that there will be sufficient wind energy as the winds are stronger with varying atmospheric (air) pressure. A maximum wind density of 196.88W/m^2 was found in the coastal areas at a height of up to 100m [10]. The maximum wind power density was observed in Lagos Ikeja.

3.2.2 Output power analysis

The wind speed data was obtained by scaling to 135m height above seas level. Studies show that wind power density is maximum at higher heights so we settle on the hub height of the case study turbine [5], [7]. Wind density power can be seen as the energy produced at a wind speed per the area swept by the rotor. The efficiency of the wind turbine is gotten by its rated rotor productivity. The corresponding output power can be gotten from the power curve of this turbine obtained from the device datasheet [24]. It can be gotten from the nameplate of the turbine. The actual values are presented in the results section. High wind speed leads to high rated rotor productivity, and the turbine achieves a higher capacity factor.[37]

The capacity factor is the ratio of the power generated per year to the product of the rated power and time, as shown in equation (3) [31].

$$CF = \frac{\text{Generated Power (MW/year)}}{\text{Rated Power (MW)} \times T(\text{hour/year})} \dots \dots \dots (3)$$

Array spacing is needed in the calculation of the number of turbine to be installed, the formula for the array spacing is given in equation (4)

$$\text{Array Spacing} = r^2 * DW * CW \dots \dots \dots (4)$$

where ; $DW = \text{Downwind spacing} = 5$
 $CW = \text{Crosswind spacing} = 10$
 $r = \text{rotor diameter}$

The number of turbines is now calculated using equation (4). To do this we estimate the total available area that surrounds the southern coastal areas in Nigeria using data retrieved from GEBCO (General Bathymetry Chart of the Oceans)

$$\text{Number of turbines} = \frac{\text{Total Available area}}{\text{Array spacing}} \dots \dots \dots (5)$$

From turbines number, the total installed capacity in megawatts can be determined. This is done by multiplying rated power gotten from the name plate with the turbine number gotten in equation 5.

4. Results

The number of turbines depends on the installation area, which is determined by the bathymetry and the exclusive economic zone. As mentioned earlier, for an effective assessment of the technical factors considered, we divided the possibly available area into three as shown in Table 2, and an analysis was carried out on these three areas, given an estimated area from the bathymetry data represented in [7], which is proportional to the individual distances from the shore and an array spacing of 2420km. Table 2 shows each depth and the corresponding available area considered without any restrictions applied. These values will reduce a bit when we consider the exclusive economic zone, which was not considered in this analysis. From this, it is clear that the area available offshore is more than at shore and increases the deeper we go into the sea with nothing less than 23000km^2 for depths beyond 50m.

Table 2: Shows the depth and area considered

	<i>At the Shore</i>	<i>Offshore (less than 50m)</i>	<i>50m and beyond</i>
<i>Distance (m)</i>	0	100	< 100
<i>Area (km²)</i>	22000	23000	< 23000

Using the data in table 2, the turbine number, the average output (MW), capacity factor, and annual energy generated can be computed using equation (3) and (4). Table 3 shows the offshore wind energy potential of the proposed wind farm. Based on the array spacing, the estimated possible number of turbines in each area were obtained, with an array spacing that is constant. Since the same turbine is proposed throughout the installation, the number of turbines increases the deeper we go offshore.

Table 3: Area available, Nameplate power output and annual energy generated

	<i>At the Shore</i>	<i>Offshore (less than 50m)</i>	<i>50m and beyond</i>
<i>Area(km²)</i>	22000	23000	< 23000
<i>Number of Turbines</i>	15589	16298	< 16298
<i>Nameplate Output Power (MW)</i>	124712	130384	< 130384
<i>Average Output (MW)</i>	54562	57043	< 57043
Actual Average Output (MW)	21824	22817	< 22817
<i>Capacity Factor</i>	0.44	0.44	< 0.44
<i>Annual energy Generation (TWh/year)</i>	478	500	< 500
Actual Annual Energy Generation (TWh/year)	191.2	200	<200

The annual generation(s) from Table 3 are more than enough to provide for the entire Lagos, having not considered the exclusive economic zones. From the result in Table 3, it can be seen that the offshore potential, if harnessed from both a farm at the shore and offshore, will add up to a total of 391.2TWh annually, with the individual energy generated being sufficient as stand-alone supply. The actual average output in MW was obtained having considered the maximum efficiency of a wind farm which is 40% of the calculated output from the nameplate.

When the turbine is placed at the shore, the turbine's average output is 21824MW, and the annual energy generation is 191.2TWh. This is more than twice the requirement for Lagos state energy demand but may not be as economical and convenient as the completely offshore farm due to the port in Lagos. Another essential thing to note is that the turbine used in this analysis has an individual output of 8MW and the average coastal wind speed is not up to its rated speed. This implies that with a turbine with higher output and lower-rated speed, we are bound to have more average energy generation annually from less turbines, which will make for less construction cost and time.

5. Conclusion and recommendation

In this study, the technical offshore wind energy was analysed, and it can be seen that the annual energy generated using aerodyne SCD 8.0/168 at the shore is **191.2TWh** and offshore, we can have 200TWh and beyond, which is more than the electrical power demand in Lagos state annually. The

most efficient depth for the current target energy demand will be between the shore and 50m deep offshore. This will help avoid the need for alterations of existing structures at the shore and the use of anchors for the floating foundations. Building the farm within this depth will be most practical as well, considering that the annual energy generation is over 4 times the demand and the generation is just nothing less than 8.8TWh away from the deep waters. The wind potential energy at the shore is 191.2TWh/year and has the capacity to meet the energy demand in Lagos per year.

Also, to avoid wake effects and to achieve efficiency. The wind speed data used was gotten from and compared to various researches done on wind speed in Nigeria by different researchers. No restriction or considerations like MPZ (Marine Protection Zone), commercial fishing, etc. were implemented because no such data was gotten. Further work can be done on the losses during transmission of power to the system operation unit and the cost of carrying out the proposed work.

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