Wind energy generation from Nigeria continental shelf: A review.

A A Attabo, O O Ajayi¹ and S O Oyedepo
Mechanical Engineering Department, Covenant University, P.M.B. 1023, Ota, Ogun State, Nigeria.
E-mail: oluseyi.ajayi@covenantuniversity.edu.ng

Abstract. The menace of global warming and increase of green-house gases have motivated many countries to embrace renewable energy sources as an alternative to fossil fuels. Some of the means by which sustainable energy is tapped are solar, biofuel, and wind. Wind energy have been around for quite some time and the power in the wind have been harnessed on land. However, due to some constraints related to land use, visual impacts and turbulence induced by buildings and trees, offshore wind farms have been engaged to provide quality alternative to onshore wind energy. This study reviews various works that have been done in the offshore wind development and tries to make a case for the generation of electricity from this type of renewable energy source to boost the nation’s electricity demand. Work done in offshore energy assessment, wake models, offshore turbine layout, future innovation in offshore wind turbine and Nigeria onshore energy scenario were reviewed. To speed up development of offshore wind energy in Nigeria, recommendation was made for government to invest in wind energy research, industries that operate in the offshore region should be willing to share meteorological data with researchers and tertiary institutions should encourage student to work on “issue-based” projects like proffering solution to the energy deficit crisis in the country.

Introduction
Unsteady oil prices, increase in energy demand and the reality of global warming has led to the push for cleaner sources of energy. One of such clean energy resources is wind energy and extracting energy from the wind is one of the oldest methods of tapping energy from nature. This can be traced back to pre-historic times i.e. about 3000 BC, where sailing boats were propelled using thrust from the wind [1]. The use of wind energy can also be found in olden day agriculture where wind energy was used to pump water from wells for irrigation, fill cattle water troughs and for grinding grain [2]. In the instances above, the wind energy was converted into torque by means of a spinning rotor and a shaft.

Experience from the oil and gas industry in offshore installations and foundations motivated the construction of wind turbine offshore, where the wind is stronger and steadier [3,4]. The desire to create more reliable and cheaper energy per unit price has led to the quest of adventuring offshore to install wind turbines [5]. Offshore wind turbines are wind Turbines installed in bodies of water for the purpose of electricity generation. According to [2,6] installation of wind farms offshore has gained momentum in Europe and it is expected to be the next big step in wind energy development. Some examples of notable offshore wind farms are the Ormode offshore wind farm shown as plate 1.1 and the Rev Horns and London array farm. As at February 2019, the total installed capacity for wind power was reported to be 600 GW [7], 4% of these wind power turbines where installed offshore [8]. With reference to the high capital cost that might be involved in foundation and logistics in moving materials offshore, installations of wind turbines have been on the increase in recent years [9].
The exploration of offshore wind resources is quite novel and has yielded positive results in Europe. Other motivation for investing in offshore Wind farms includes the scarceness of suitable land that have sufficient wind speed, visual impact, environmental issues related to eddy noise from wind turbines, impact on bird life and flickering shadow from rotating turbine blade [10,11]. When compared to onshore wind resources in most parts of the world, offshore wind resources have been reported to possess higher potential, and the wind speed tend to increase as one move further into sea (i.e. further away from the shoreline). This therefore results to considerably higher energy yield, as the power output from a wind turbine is theoretically a function of the cube of the average wind speed [12].

1. Statement of problem
Power generation is the core of both technological and economic development of any nation as it is the bedrock of many crucial sectors of the economy for example, constant power is required in health sector for the preservation of drugs and vaccines, it is used to run machines in industries, schools need energy to run laboratories and multimedia learning equipment, streets lightings and state security gadgets all require electricity to work. The aforementioned make electricity generation and its distribution a very sensitive issue with several economic complexities therefore making the success of nations hinged on it. Sadly, Nigeria is still struggling with the generation of energy to meet her growing population of which a large percentage are youth who use electrical gadgets and equipment heavily [13,14].

Hydro and thermal plants are the two commercially available energy generating systems in the country. This is relatively low energy generation mix as it can easily drive the nation into energy crisis because the unavailability of one of the resources will strain the national grid. With the unpleasant security situation in Nigeria and youth restiveness in most south-south areas of Nigeria [15], frequent sabotage on gas supply pipelines that feed the thermal power plants which have led to unplanned shutdown of the thermal power plants in Nigeria [16]. Finally, the use of fossil fuel for electric generation have been a major culprit in the emission of greenhouse gases [17].

2. Background of offshore wind farms
The first known wind farm that was installed offshore was Vindeby offshore wind farm and it started operation in 1991 by DONG energy in Lolland, Denmark. The wind farm was made up of 11 units of wind turbines rated 450 kW each, located in a site that is 4 m deep and 2 km away from the shoreline. After 26 years of operation, the Vindeby wind farm was decommissioned in 2017 with gross electricity production of about 234 GWh. After the successful commissioning and operation of the Vindeby farm, many other offshore wind farms began to spring up, this led to an exponential growth in the development of offshore turbines with larger capacity and deeper water depths. At the end of
2014, about 3,230 turbines (in 84 offshore farms) had been commissioned in 11 European countries and grid-connected, with total capacity of about 11,027 MW [13].

### Review of various studies on offshore wind energy

Works carried out on the development of wind energy were categorized into various sub topics reviewed as outlined below.

#### 2.1. Review of offshore wind energy assessment

Oh et al. [14] investigated the wind potential around the south-western area of the Korean Peninsula. Wind potential in the projected site was measured using a meteorological mast constructed offshore in conjunction with Metrological and oceanographic special Research unit. Data obtained from the metrological mast and other adjoining areas where used to analyse the sea surface roughness, diurnal and seasonal variations in wind speed, wind direction pattern and estimation of wind speed using Measure-Correlate-Predict (MCP) model. The wind energy potential of the site was reported to be in class 3 regime but the effect of wake within the prospective wind farm was not considered.

Adaramola et al. [15] used the Weibull probability function to examine the wind speed characteristics in Ghana for the purpose of electricity generation. The six coastal locations that were studied are Warabeba, Oshiyie, Mankoadze, Aplaku, Anloga and Adafoah. Wind speed data was obtained from Ghana Energy commission at a height of 12 m. Results from the study indicates that wind resource along the coastal region can be classified into Class 2 or lower, thereby making the region suitable for marginal wind energy development. The recommendation was to use wind turbines having cut-in wind speed of < 3 m/s and 9-11 m/s rated wind speed to increase turbine availability factor. The study further proposed CF-100 to be the most suitable wind turbine model for the coastal region of Ghana and using that model of wind turbine, the estimated unit cost of electricity was reported to be between 0.01$/kWh and 0.05$/kWh. The effect of turbine induced wake was not considered in the paper.

Michael et al. [16] evaluated the wind resource available in California’s offshore area using a mesoscale atmospheric model developed by the Pennsylvania State atmospheric research center called Mesoscale Model version 5 (MM5). Results from this mesoscale was then authenticated with results from measurement buoys with high resolution bathymetry image located in the ocean. The wind speeds were measured at 80 m turbine hub height for the project using monthly average for the month of January, April, July, and October of 2005 and 2006, the study also examined mean speed for the whole months in 2007. Resource assessment of the region was carried out using a 5 MW offshore turbine and key factors considered for the work were transmission access, water depth and legislation. In the study, offshore areas where wind speed at 80 m height were 7.5 m/s and higher were considered to be suitable for offshore wind development and their result showed that power generation could range between 1.4 and 64.9 GW (daily or annually). Based on the type of foundation type, power generation was categorized as follows: 1.4 - 2.3 GW could be generated using monopile, 4.4 - 8.3 GW could be generated using jacket type foundation and wind farms using floating turbine foundations could yield 52.8 - 64.9 GW of power annually. Diurnal variation for the area studied was found to be relatively stable hence power generation was possible and consistent both day and night for the whole year however reference was not made to the effect of turbine wake on wind energy potential.

Ahmmad [17] evaluated the wind energy potential in Bangladesh using a hybrid wind conversion system with a battery storage system. Data collected from the meteorological centres were analysed using the Rayleigh distribution functions. The results showed the hybrid system has an annual mean wind power profile and power density of 2351.76 K/hr and 194.2 W/m² respectively. The study used wind speed information retrieved from the Dhaka airport station.

To estimate the potential of wind energy available in the coastal area of Ceara, Brazil Lima et al. [18] used a computer based atmospheric model called Regional Atmospheric System (RAMS) that can predict mesoscale wind data at high resolution. The application was set at a 2 km horizontal resolution to estimate the offshore average wind speed for both dry and wet seasons, predominant wind direction and wind turbulence between 1996-2012. Numerical simulation results were then validated with measured data at 60.4 m and correlation between the two data set was satisfactory. Results from the study indicated that mean wind speed was about 8 m/s and calculated power density...
of the area was about 720 W/m² for all seasons. Wind direction was predominantly from east to west for the dry season while the turbulence intensity was also calculated to be lower during this season compared to the wet season. Moreover, the validation of results was not done for some period between 1997 and 1998.

Satir et al. [19] evaluated the coastal areas of Turkey using the windPro software to analyse the suitability of the area for wind power generation. Bozcaada area was recommended for offshore wind farm installation because it was observed to possess the highest wind potential. Technical analysis was conducted using Siemens SWT-3.6-120 and Vestas V90-3.0 wind turbines and annual energy production from the two turbines were given as 322,911 MWh/yr and 454,326 MWh/yr respectively. However, the work used 1 year of data which is not usually sufficient to carry out robust wind resource analysis.

2.2. Review of studies that used Numerical Analysis for prediction of wind speeds

Monfared et al. [20] proposed a model for the prediction of wind speeds using fuzzy logic and artificial neural network. In the study, standard deviation, average and slope of the measured wind speeds were inputted in the fuzzy logic to improve the prediction of the model. The feed-forward neural network was used and the ANN was trained using a standard back propagation algorithm. The neural network was trained with 672 wind data samples from February to November 2007 and result from the work suggest that this method reduces computation time.

Li and Shi [21] carried out a comparative study of the application of three types of artificial neural networks as it applies to wind speed forecasting. It studied the following models: back propagation, adaptive linear element and radial basis function. Two observatory sites in North Dakota were used for the study and hourly mean wind speeds were collected. The three metrics used for the evaluation of the ANN are the root mean square error, mean absolute error and mean absolute percentage error. Results from showed that, no single artificial neural network model outclasses others even for the same data set. The work also recommended the use of robust post-processing method in forecasting wind speeds for better accuracy.

Fadare [22] modelled and predicted wind speed in Nigeria using a 3-layered, feed-forward, back-propagation artificial neural network (ANN) model. The ANN model was designed using the Neural Toolbox for MATLAB while the training and testing of the model was carried out using monthly and daily mean wind speed data monitored at 10 m height obtained from the Nigeria Meteorological Services (NIMET). Result from the work showed that the correlation coefficient (r) between the predicted and the measured wind speed was obtained as 0.9380. Average monthly wind speed predicted for the 28 onshore metrological stations studied ranged from 0.9 to 13.1 m/s and annual mean speed was 4.7 m/s.

Koletsis et al. [23] researched further, to evaluate the effect of climate change on wind energy developments in the Black Sea and Mediterranean Sea using ENSEMBLES project software. The study covered the past climate of 1961 to 1990, predicted climate regime from 2021 to 2050 and 2061 to 2090. The estimated wind speeds and resultant wind power potential showed a reduction in average wind speed in areas around major parts of the Mediterranean Sea. However, increase in wind speed was noted in the Gulf of Lion, Alboran and Aegean seas. The prediction showed some areas where there are mutual future trend, but there was disagreement in the specific locations where these change will occur and the magnitude of the predicted change.

Sasaki [24] used numerical models to predict offshore wind and wave power globally considering 9 days look-ahead using various wave and wind models for the period 2008–2012. Wave power was calculated using a wave model termed “third-generation” model which was developed at the US National Oceanic and Atmospheric Administration – National Center for Environmental Prediction while the near-surface wind data from the ERA-Interim reanalysis was used to simulate wind power available offshore. To validate the accuracy of predicted wind and wave speeds, the results were statistically evaluated using the ensemble spread, mean prediction error and anomaly correlation coefficient (ACC). Results from their study showed that wave power can be predicted over vast zones of the global ocean with prediction error less than 20% for 3 days lead time but predictability of ocean wind speed showed lower correlation between the measure and predicted values using the ACC method.
2.3. Review of GIS methods for Offshore wind energy estimations

Ho et al. [25] evaluated the offshore wind potential in Malaysia with the aid of two GIS methods (the QuikSCAT and the WindSat) in estimating the potential energy inherent in offshore wind in the region. Annual average wind speed of 6-7 m/s at 50 m was observed throughout the year hence, the study made strong recommendation to the government and private investors to commence investment in power generation from offshore wind resources in Malaysia. However, the study did not validate GIS data with actual field data and cost analysis of intended wind project was not investigated.

Cavazzi and Dutton [26] developed an Offshore Wind Energy Geographic Information System (OWE-GIS) which was used in determining wind energy resource in United Kingdom’s offshore sites. In the system, cost projections of offshore farms were estimated using; development costs based on water depth, potential annual energy production dependent on the locations’ wind speed distribution, turbine availability, project lifetime and discount rate on capital expenditure used in executing the project. Results from the study showed that 150 GW of electricity can be produced form 10% of accessible UK waters at a production price lower than 280 $/MWh. Validation of GIS generated data with field data was not performed, as all cost estimation was done using only the novel model.

Garlapati et al. [27] used two years (2012-2013) OSCAT satellite data to determine the offshore wind energy resources in India. A Geographical Information System (GIS) was used to generate wind maps at 80 m taken to be the turbine height. The study showed that about 74% of the area of interest has class 1 wind speeds, annual average wind speed and wind power density were calculated to be 9.7-13.4 m/s and 1048.7-1632.5 W/m2 respectively. Using a 2.1 MW rated capacity wind turbine and matured offshore foundation type for analysis, the average annual output power excluding conflict areas was found to be approximately 1738.6 GW. However, the study used only two years’ data for the analysis as against 10 years or more which would have been more suitable to cover for climate change variation.

Ulazia et al. [28] evaluated the suitability of various Weather Research and Forecasting (WRF) meteorological models in estimating wind speeds for energy conversion systems. The focus of the work was in the Bay of Biscay (i.e. around the Iberian northern coastline) between 1990 to 2001. WRF models that was used captured wind speeds at different time intervals of 24 hrs, 12 hrs and 6 hrs. Using surface wind data acquired from the Cross-Calibrated Multi-Platform (CCMP), a spatially distributed analysis was conducted for the region. The predictions from satellites data were validated with wind data obtained from observatory buoys. Result from the study revealed that the wind speed values obtained at data frequency of six hours yielded the best verification scores at a 95% confidence level, thereby being the most accurate at reproducing wind observations in the area. The study did not carry out econometrics of offshore wind turbines.

Zheng et al. [29] reviewed the various models that can be used for the estimation of offshore wind resources, noting the fact that it is not economically practicable to carry out continuous real time measurements on the sea for preliminary investigation of offshore wind energy potential. Some of the applications they reviewed were Quicksat, SatWind, Wind Atlas Analysis and Application Program (WAsP), SiteWind, Wind energy Simulating Toolkit, wind energy Power Prediction Tool (WPPT) and the use of Synthetic Aperture Radars (SAR). The study did not cover wind energy economics.

Scarcity of in-situ wind data at offshore locations in India motivated Gadad and Deka [30] to study the applicability of using Oceansat-2 scatterometer (OSCAT) to measure the speed of wind and wind power density in and around the Indian Ocean. The research assessed the power inherent in the offshore wind around Karnataka state using continuous measured satellite data that its precision was validated with INCOIS Real-time All-Weather Station (IRAWS) data. Power generation capacity evaluation was conducted using a Repower 5 MW wind turbine as the test turbine and two years (2011 and 2012) mean wind speeds obtained from the satellite. Results from the study showed that 9,091 MW of electricity could be generated using Monopile foundation (0–35 m water depth), about 12,000 MW with Jacket (35–50 m water depth), 24,000 MW using advanced Jacket (50–100 m water depth) and 118,000 MW using floating foundations (100–1000 m water depth). However, the levelized cost of energy from offshore wind turbines was not considered.

In a similar study, Nagababu et al. [31] used 14 years GIS information retrieved from European Centre for Medium-range Weather Forecasting to analyse available wind energy potential in the coast of India. Wind speed was simulated at a hub height of 80 m and wind turbine manufactured by
Gamesa (Model -G128- 5MW) was used for LCOE computations. For maximum energy yield, the study suggested coastal towns of Tamil-Nadu and Gujarat for the installation of offshore wind farms. The western coast of India was estimated to have wind power density between 13-294 W/m² and while technical potential was about 38.7 TWh. On the other hand, the estimated values for wind energy potential and technical potential for the eastern coast of India are between 63-393 W/m² and 58.4 TWh respectively. This potential is about 42% of India’s wind energy capacity however, validation of GIS data and field metrological data was not done.

Amirinia et al. [32] used GIS method to assess the potential of offshore wind in the Gulf of Persia. The study used uncertainty analysis method to estimate the wind potential in the area. The uncertainties considered in the study were sea surface roughness, wind power production and air density variation. The study evaluated 25-years (1984-2008) data acquired from ECMWF (European Center for Medium-Range Weather Forecasts) and then using the Monte Carlo simulation method, long term wind energy and speed were estimated. The study reports a 5.3% reduction in energy produced from the area when compared with conventional method, i.e. that the region can generate up to 2,980 GWh per year. A figure which is about 5.3% lower than outcomes from studies that used conventional analytical methods. Econometric study of the region reported that if the interest rate on capital was at 15%, operating wind energy turbines in the area cannot be competitive compared to the rate of energy production globally. However, if the interest rate is reduced by 10% (i.e. interest rate of 5%), some parts of the region will be able to generate electricity at a competitive price.

Carvalho et al. [33] carried out comparative experiment using offshore wind speeds acquired via remote measurements methods with the wind data obtained from equipment mounted on buoys located around the Atlantic coast (Iberian Peninsula). The study proved that GIS method is a credible alternative for measuring offshore wind speeds when physical measurement was not possible. It used Advanced-Scatterometer (ASCAT) of the European Space Agency, the Indian Space Research Organization's Oceansat-2 Scatterometer (OSCAT) and a numerical weather prediction model. Their result showed that ASCAT has the low variations and wind power flux estimation errors while the Weather Research and Forecast (WRF) model gave the best prediction for mean wind speed hence the study recommends using it for estimation of wind speed and weibull probability density functions offshore. The study however did not consider the levelised cost of energy produced from the wind turbines located offshore.

Schallenberg-Rodríguez and Montesdeoca [34] used the ArGIS method to investigate the energy potential in the wind around the Canary Island and reported the wind power potential to be 57 GW. The study used 515 units of 5 MW offshore turbines with fixed bottom foundations on an ocean area of 180 km². The estimated energy production from the region was 3 times higher than the energy demand of the area. However, precise wake deficit as it affects the planned turbine array was not considered in the study.

2.4. Reviews on Turbine wake

This section presents some works that have been carried out to evaluate wake deficit in wind farms for better estimation of energy production. These studies include those of Kusiak and Song [35] which used generic model with few constraints considered while making assumption to estimate wake loss in wind farms. By transforming the constraints into second objective function, a multi facet algorithm was established to solve the turbine wake optimization problem. Solving this problem maximized output from the wind farm and reduces failure rate of the blades. The work focused only on one terrain type which was high speed terrains with large turbines.

Barthelmie and Jensen [36] developed a novel wake model which was for the wake prediction for Nysted offshore wind farm in Denmark. Comparing the novel model with WASP, it reported that deep array effect (wake loss in the center) was underestimated by WASP. One of the key recommendations from the study was that a wake decay coefficient of 0.03 is a better fit for the Nysted farm. The work was also carried out on an established wind farm hence wind resource assessment was not looked into.

Gaumond et al. [37] compared various wake models using the Horns Rev and Lillgrund farms located in Sweden and Denmark respectively. The study reported that the wake models evaluated presented large prediction error due to the fact that the distance between turbines are
relatively small and the effect of turbine wake still affect the inner array turbines. The constant change in wind direction was one of the reasons for discrepancy between predicted wake deficit and actual deficit in energy produced from the wind farms. Work was carried out on existing wind farm hence consideration was not given to production cost and wind farm resource assessment.

Seim [38] evaluated three kinematic wake models which was validated on the WindSim software to test eight single wake cases in complex terrain condition. Result from the work showed that the Larsen's model predicted a wake whose width was overestimated. However, the model predicted a constant offset location thereby reducing the ambiguity involved in computing the overall power output from the wind farm. Jeon et al. [39] did a similar work in comparing various wake models head-to-head to check their accuracy. The study noted that the Jensen wake model gave a better prediction than both the Larsen and Eddy viscosity models. Albeit, the width of the wake was predicted with higher accuracy using the Eddy viscosity and Larsen models.

Niayifar and Porte-Agel [40] tested a proprietary analytical model which was developed for prediction of power loss as a result of turbine wakes in a wind farm. Field data obtained from the Horns Rev farm with turbine power curve from Vesta V-80 turbines was used in the study. Local wake growth was simulated by the superposition of velocity deficits from multiple wakes and validated using large Eddies Simulation (LES). Results from the studies suggest that the power prediction using application like WASP is overestimated and their model showed better approximation of power produced from the farm.

Hou et al. [41] used the Mixed Integer Particle Swarm Optimization (MIPSO) algorithm in analyzing yield obtained from a wind farm and compared the result with a reference wind farm layout developed by the Norwegian Centre for Offshore Wind Energy (NORCOWE). Findings from the study established a 5% decrease in Levelized Energy cost and about 3.82% rise in energy yield. The study used the Horns Rev offshore farm as a case study. However, installation cost and foundation cost were not considered in the wind farm optimization algorithm.

2.5. Review on wind Turbine Layout
Attias and Ladany [42] formulated a discrete model to improve energy yields from wind farm with the resultant aim of increasing Net Present Value and the Internal Rate of Return of the wind farm. The study evaluated downwind turbines in a rectangular array, same turbine types assumed to have the same hub height. The study recommended that for maximum return on investment, turbine array of 24 units to be used with 4 row x 6 column will yield about 19.7% return on investment. Using the wind turbine layout optimization program (Multi-Population Genetic Algorithm).

Gao [43] optimized the arrangement of four theoretical offshore wind farms at the coast of Hong Kong. An area of about 357.78 km² was evaluated using 10 years’ wind data obtained from government agencies. It calculated the cost of energy of the farms after optimization to range from 0.23 $/kWh to 1.52 $/kWh, payback time ranged from 14.44 years to 75.89 years. The effect of wake was considered with wind direction from all directions, the study developed a model named ‘Wind Farm Power Generation Calculation Tools’ (WFPGCTs) which the study recommends for calculation of wind power after the layout of the farm is established.

Shakoor et al. [44] reviewed different far wake models to evaluate the accuracy in prediction. It focused on the studies on wind farm layout optimization while paying attention to far wake models. The findings showed that 75% work on wind energy farm optimization used the generic algorithm. Hence, it was suggested that other optimization methods be explored to solve wind farm optimization issues.

As offshore wind turbines begin to increase Ajit et al. [45] carried out studies to optimize the layout of Middelgrunden wind farm located off the shores of Denmark. The work was carried out considering the standpoint of wind farm developers and profit maximization during the planning phase of future offshore wind farms. It designed new layouts for the farm using a generic algorithm (GA) and particle swarm optimization (PSO). These new layouts were then compared with the existing wind farm. Results from the study showed that both GA and PSO can improve yields from the layouts by a resultant 1-3.5% reduction in levelized cost of energy compared to the existing layout. Subsequently, notable recommendations were made for the use of advance algorithms during wind farm layouts because this will result in substantial savings over the lifetime of the wind farm. Ou et al. [46]
researched into development of practical zoning method for offshore wind farms in 10 coastal provinces in China. The Maritime Spatial Planning method was used to avoid the haphazard location of Offshore Wind Farm (OWF) in China waters. The study considered a time frame of 2011 to 2020 and zoning was based on the factors such as sea use status, demand for energy, environmental considerations and distance to shore. The results show that offshore wind farms sites can be such that it will co-exist with other economic activities like fishing, light-to-medium water transportation and industrial zone if it is well planned. The actual energy that can be produced form the region was however not considered in the study.

Amaral and Castro [47] used a novel approach they called the deterministic algorithm to predict on offshore wind park with 8 wind turbines arranged in two rows. The model was validated with the generic algorithm and particle swarm optimization models. The comparison was satisfactory as the optimization algorithms reached very good estimates of the annual energy produced, after 100 experiments the error of the generic algorithm was 0.03%.

2.6. Review of Offshore Turbine Logistics
Green and Vasilakos [48] made a research on the economies of offshore winds using the development of offshore wind turbine (OWT) in the European Union as a case study. It acknowledged the fact that installation cost for OWT is relatively high hence, there is need for government support in terms of grants, reduction in investors taxes and waivers where applicable. Some recommendation made include the development of hybrid foundation type (where OWT foundations can be used for other economic benefits), use of dual distribution lines for sales of electricity to various locations based on demand and the provision of green certificate for units of energy produced by the OWT. Moreover, it is worthy of note that improper planning during the installation of offshore wind turbine could lead to increased over-head cost which in turn will lead to increase in capital expenditure and reduced returns on investments. This assertion motivated Iris and Evrim [49] to carry out a study on the logistics of installing offshore wind farms. The study pointed that the installation of offshore wind farm (OWF) is highly complex, due to the high dependence on weather and the oversized components that might be complex to lift or transported. The study further analysed actual projects that were executed in the North Sea region and their findings revealed the major components to be pre-assembled from shore, the ideal vessel load to be used for transporting loads and the distance to shore. It therefore strongly recommended pre-assembling of turbine parts onshore thereby reducing the number of parts that will be installed on site.

He et al. [50] used the Strength Weakness Opportunity and Threat (SWOT) analysis method to evaluate both the external and internal factors affecting the development of the Chinese offshore power sector. The study shows that offshore wind technology has the following strengths: abundant wind resources, possibility of combining offshore wind generation with tidal turbines and environmental friendliness. Moreover, the drawbacks include high cost, lack of a local manufacturer (in China as at time of the research) and lack of coordination among departments. To enhance the strengths of offshore wind farms the study therefore proposed the need for more research to be carried out on OWT technology with the aim of cost reduction in foundation cost and increase reliability of the turbines.

Colmenar-Santos et al. [51] reviewed the status of offshore wind energy development in Spain considering the fact that steady growth have been made in the industry worldwide but Spain is yet to benefit from this technology. It referenced counties which have made giant strides in offshore wind energy technology, like Denmark, Holland, Sweden, Germany and United Kingdom. Notable hindrances to the development of offshore winds are listed to include social disapproval to installations near the coast, deep coastal seabed characteristics and absence of a stable regulatory policy for the establishment of offshore wind farm. Furthermore, it made recommendation for the establishment of a policy to encourage investment of offshore wind farm in Spain as preliminary resource assessment have shown that the region is viable for this type of renewable energy development. On the other hand, Sarker and Faiz [52] designed a model based on variables that affect installation of offshore wind farm. These variables include number of parts to be installed on site, turbine rated output, lifting capacity of crane, vessel deck and distance of port to farm. Numerical analysis was then performed to illustrate the model and to understand the general behaviour of
different system parameters. The aim of the work was to minimize cost of installation and a key recommendation was to encourage preassembly of turbine parts on land before moving them offshore as dynamic lifting operations requires more time and specialty to handle. It also noted that total cost is highly impacted by turbine size and routine/scheduled maintenance help reduce the cost of maintenance.

2.7. Reviews on novel approach to Offshore Wind Farms

Katsaprakakis and Christakis [53] investigated the technical and economic feasibility of using an offshore wind farm combined with Wind Powered Pumped Storage System (WP-PSS) at a location in Rhodes island. The concept is for the wind turbine to pump water into an elevated reservoir during period of high winds and the power can later be extracted from the water through a hydro turbine when the wind speed reduces. To increase the reliability of the wind park, it suggested that larger reservoirs and double penstocks should be use in designing the system as it will allow greater water reserve capacity and the simultaneous water fall from the penstocks will improve the hydro-turbine efficiency. Further to this, the study created an algorithm to simulate the action of the WP-PSS with two autonomous pipelines, one mainly for water fall and the other for pumping water, thereby making it possible for the simultaneous storage of energy and production of energy. Feasibility study was carried out using wind potential measurements captured from October 2009-March 2010 (six months) in conjunction with the WAsP software developed by Technical University of Denmark and a wind atlas of the proposed site. It also established the fact that a WP-PSS can be used in areas with marginal wind potential but have available land space. Result from the study shows that the WP-PSS model is feasible and could lead to an annual wind energy production that is 50% greater than the annual wind potential available in that site.

Michailides et al. [54] evaluated the operation of an offshore wind turbine combined with semi-submersible wind energy and Flap-type wave energy Converter (SFC) in extreme environmental conditions. The SFC is a combined equipment with a semi-submersible floating wind turbine and three fully submerged rotating flap-type Wave Energy Converters. The study developed a numerical model using the software Simo-Riflex (developed by MARINTEK). To validate their numerical results, a 1:50 scale model was built and load tests were conducted on it. Some of the load tested were static, quasi-static, regular waves and asymmetrical waves in windy conditions. The response of the SFC in regular waves (with absence of wind loading) was investigated considering fourteen different wave periods. Results showed satisfactory correlation between experimental data and predictions made with numerical models to validate the correctness of the numerical models.

Tsai et al. [55] studied the patents granted by the United States Patent and Trademark Office (USPTO) and the European Patent Office (EPO) in the offshore wind sector and results from the study showed that 59% of patents in 2014 were granted in this field. A review of patents collected indicated that technologies associated with engineering vessels, floating foundations, turbine installations, integration of multiple technologies, tower and mooring system were the researched areas for OWT development.

Qin et al. [56] proposed a novel method for storage of energy produced from offshore wind farms to compensate for wind variations, energy storage to compensate for loss of power due to wind variation. The aim of the study was to reduce the disparity between energy demand and energy generated from wind farms. Experiment was carried out using an offshore wind farm in Richmond Virginia by retrofitting the turbines with hydraulic power transmission (HPT) and Compressed Air Energy Storage (CAES) system. The HPT was installed in the nacelle of the turbine and it comprises a hydraulic pump with high compression ratio that can convert the wind energy into pressure energy; when the energy demand is low, the excess pressure is stored as compressed air in a receiver located at the base of the turbine tower. During low wind scenario and energy is demanded, the compressed air expands through the CAES system to generate power, hence meeting the energy demand. The study then used a cost and scaling model developed by the National Renewable Experimental laboratory for cost analysis and result showed that retrofitting conventional turbines with CAES and HPT can increase savings to about 21.6% if the turbine operates for 20-years.
2.8. Review of Nigeria Onshore Wind Energy Potential

Ajayi et al. [57] assessed the potential of wind energy in Shaki and Iseyin (two sites in south West Nigeria) using the Weibull two parameter distribution. 21 years’ (i.e. 1987-2007) monthly average wind data was used to investigate monthly, seasonal and yearly wind characteristics and potential for the sites. The study recommended that wind turbine models with cut-in speed of 3 m/s, cut-out-speed of 25 m/s and rated wind speed of 11.6 m/s will be viable for small scale electricity generation in the sites. The study also showed that the generation of few Giga-Watt hours of electricity is possible at sites with average cost of electricity not higher than €0.049 per kWh.

Ohunakin [58] statistically analysed the characteristics of wind in five selected sites in some Nigeria North-central states, the locations investigated are Lokoja, Ilorin, Makurdi, Bida and Minna using wind speed data between 1971 to 2007 and the Weibull distribution function. Result from the study showed that the mean annual wind speeds are 3.158, 4.386, 4.570, 2.747 and 4.289 m/s for Lokoja, Ilorin, Makurdi, Bida and Minna respectively. Hence, none of the sites was recommended as a profitable site for large scale wind farm investment. Cost analysis for siting wind farm in the North central region of Nigeria was also evaluated by Ademola et al. [59] using a 37 years’ wind data information. The results showed that Minna has the highest potential to be used as a site for wind power generation, while wind data for Bida showed it to have the least wind energy potential amongst the sites considered. The study also shows that if inflation rate increases from 0% to about 5%, the energy cost will drop by 29% and the return on investment will also reduce from about 12% to 6%.

In a similar study, Oyedepo et al. [60] examined wind potential for three eastern sites in Nigeria (Enugu, Owerri, and Onitsha) using wind data from NIMET that was captured at a height of 10 m. The annual mean speed for Enugu, Owerri and Onitsha were reported to be 5.4, 3.4 and 3.6 m/s, respectively, while the yearly wind speed carrying maximum energy for the site is given to be 6.5, 4.3 and 3.9 m/s. The study also simulated the performance of a windmill with rated power of 0.36 kW for pumping water and it reported a monthly mean water produced by the rotodynamic pump to be 3,442, 2,730 and 2,530 m$^3$ for Enugu, Onitsha and Owerri respectively.

Ajayi et al. [61] used the Weibull probability density with two-parameter function to analyse electricity generation potential from wind in Kano. The result showed that the mean monthly wind speed ranged from 6.6 m/s to 9.5 m/s. When comparing seasonal variations in wind speeds between dry and wet season, the wet season had a higher mean wind speed of 9.5 m/s. Ajayi et al. [62] increased the scope of the study by evaluating the potential in wind at ten sites located in Nigeria’s south-western region using twenty-four years’ data (1987 to 2010) obtained from NIMET. Result from the study suggested that Lagos state (with mean wind speed of 2.9 m/s) and Oyo State (5.8 m/s mean wind speed) can be exploited for the generation of large-scale electricity using wind turbines while the other location could be used for standalone small to medium scale electricity generation. Five models of horizontal axis wind turbines where evaluated for the sites and GE 1.5 sle wind turbine model was recommended for use. Econometrics shows that electricity generation cost ranged from 0.04 $/kWh to 5.03 $/kWh, based on the model of turbine used.

Abdulkarim et al. [63] carried out statistical analysis to determine the frequency distribution method with the best goodness of fit using wind speed data collated from fourteen sites in Nigeria namely Abuja, Bauchi, Bida, Gombe, Gusau, Ibi, Jos, Kaduna, Kano, Katsina, Lafia, Lokoja, Makurdi, Minna and Nguru. The study evaluated Gamma, Weibull and Rayleigh distribution functions and the performances of the probability functions was rated based on the variation between the theoretical and measured wind power densities. The Weibull distribution function gave a better prediction than the other distribution functions, result from the study also stated that Jos, Kano and Minna can be used for both off grid and grid electricity generation because the sites were rated to be class 4 category wind site.

Fatigun et al. [64] assessed the energy potential available in the wind speed in Ikeja, south western Nigeria using two-parameter Weibull distribution function with data captured at 10 m. Results from the study shows that the wind turbulence in the area was higher during dry season compared to the raining season. Wind power density (WPD) extrapolated at 50 m hub height was reported to be between 116.3 W/m$^2 \leq$ WPD $\leq$423.3 W/m$^2$ with annual average of 257.9W/m$^2$. These figures suggest that the sites have marginal wind energy potential. Therefore, it was recommended for small scale electricity generation.
3. Opportunity for further wind power researches in Nigeria
From the reviewed literature, it can be seen that many works have been done on wind farm but the following opportunity for research still exist.

• Extensive wind mapping has been done for the land locations (Onshore) in Nigeria but offshore wind data is yet to be captured and analysed. Offshore wind characteristics have been reported to be more consistent with higher speed in other parts of the world but wind energy mapping of Nigeria continental shelf is yet to be done.
• Research into appropriate GIS software/model to estimate wind speed and by extension wind power for Nigeria is required.
• There is need for further research into multilayer numerical models for the prediction of wind profile in the regions of Nigeria.
• Installation of an offshore metrological station at location targeted with relatively high speeds for real-time extended period for wind speed, direction, atmospheric pressure, relative humidity and other relevant data capturing will be very adequate.

4. Recommendations for Nigeria wind energy sector development
The development of offshore wind energy and other renewable in Nigeria have not made much progress in recent years because of some inherent problems that have stunted the growth of the industry. To achieve energy sustainability and increase the country’s energy mix, there is need to consider the following recommendations:

4.1. Government incentive and policies framework
The lack of commitment from the government to execute the energy policies and framework have led to investors demoralization and withdrawal as there is no guarantee that the return on their investment will yield returns in the least possible time. It is expedient for government to show commitment and follow through with the renewable energy framework with evidence that the interest of the investors is protected even when there is a change in government. A robust regulatory and legal framework will increase the confidence of investors for renewable energies and that will translate into individuals willing to commit their time and resources into the development of renewable energy. The government should also consider granting import duty waivers, tax rebates, energy credits and other incentives to offshore wind energy investors since the project is capital intensive. Bureaucracy around energy permits and approval should be reduced so as to encourage some start-up companies to venture into renewable energy generation such as offshore wind turbine.

4.2. Institutions to emphasis R&D tailored towards wind energy projects
The role that tertiary institution plays in the development of a nation cannot be overemphasized as it serves as a hub for research and innovation. Hence, researchers and students from such institutions should be encouraged to focus on issued based projects like the development of wind power technology and work towards the development of indigenous technology that will suit the nation’s peculiar climatic environment.

4.3. Information to aid R&D to be made available to public
Institutions with relevant information and data that can aid the growth of renewable energy should make such information available for free. For example, NIMET, NIMASA etc should make wind speed information free for research institutions to download, Oil and Gas company should also be willing to share water depth, wind speeds and cost of running, with research institutions. As it stands acquiring information from these establishments for research purposes is cumbersome and creates a bottleneck for speedy development of renewable technology in the country.

5. Conclusion
Nigeria has a coastal line of about 853 km which has potential for the generation of electricity via the use of offshore wind turbines. However, technical investigation to evaluate the exact wind energy resources that abound in the shores of the country has not been carried out. This paper therefore reviewed various work that has been carried out in other countries where offshore wind turbines gained some measure of success with the aim of sensitizing research and development of offshore wind energy and by extension reduce the country’s energy deficit. This work reviewed work carried out in offshore wind resource assessment, the use of GIS methods to measure offshore wind speeds, offshore wind turbine layouts, Nigeria onshore wind assessment scenario, turbine wake deficit and future innovations in offshore wind development. For rapid development of offshore wind turbine in this region, it was recommended that the government should invest in wind energy R&D especially development of offshore wind technology, tertiary institutions to encourage students to carry out “issues based” researches like offshore wind energy development to alleviate the energy crisis in the country and marine and oil and gas industries should be willing to share wind energy data in formation with researchers to enhance ease of estimating wind energy potentials.

References

[1] Gary L J 2006 *Wind Energy Systems* (Manhattan, KS, USA)

[2] Breton S and Moe G 2009 Status, plans and technologies for offshore wind turbines in Europe and North America. *Renewable Energy* 34 646–654

[3] Schneider J and Senders M 2010 Foundation Design: A comparison of oil and gas platforms with offshore wind turbines *J. Marine Technology Society* 44(1) 32-51

[4] Chong W Z, Chong Y L, Jing P, Ming Y L and Lin L X 2016 An overview of global ocean wind energy resource evaluations. *Renewable and Sustainable Energy Reviews* 53 1240–1251

[5] Walt M, Donna H, Philipp B, George S and Caroline D 2016 Offshore Wind Energy Resource Assessment for the United States National Renewable Energy Laboratory. 2-7

[6] Graziano M, Lecca P and Musso M 2017 Historic paths and future expectations: The macroeconomic impacts of the offshore wind technologies in the UK. *Energy Policy* 108 715–730

[7] World Wind Energy Association. Press release February 25, 2019 https://wwindea.org/information-2/information/ assessed April 30th 2019

[8] International renewable Energy Agency 2018 IRENA, Renewable Energy Benefits; leveraging Local capacity for Offshore wind, 2018 report 4

[9] Adesoji A, Charles M, Benjamin C and Yohannes H 2012 Assessing offshore wind potential *Energy Policy* 42 191–200

[10] Esteban M D, Counago B, Lopez-Gutierrez J S, Negro V and Velliso F 2015 Gravity based support structures for offshore wind turbine generators: Review of the installation process. J. *Ocean Engineering* 4 1-17. DOI: 10.1016/j.oceaneng.2015.10.033

[11] Kaldellis J K and Kapsali M 2013 Shifting towards offshore wind energy—Recent activity and future development. *Energy Policy* 53 136–148

[12] Effiong S O, Nwankwojike B N and Abam F I 2016 Economic cost evaluation on the viability of offshore wind turbine farms in Nigeria. *Energy Reports* 2 48–53

[13] Onakoya A B O, Onakoya A O, Jimi-Salami O A and Odedairo B 2013 Energy consumption and Nigerian economic growth: An empirical analysis European Journal of Scientific Research 9(4) 25 -40

[14] Sama M C and Tah N R 2016 The effect of energy consumption on economic growth in Cameroon Asian Economic and Financial Review 6 (9) 510-521

[15] Akuhwa T P 2015 The Effects of Unemployment and Anti-Social Activities of Youth on Socioeconomic Development of Benue State, Nigeria J. of Humanities and Social Science 20 (8) 69-81

[16] Enyidah-OkeyOrdu G 2017 Violence, Aggression and Insecurity in the Niger Delta of Nigeria: An Exploratory Study of the Militancy in the Region J. Advances in Social Sciences Research 4 (2) 9-14
[17] Gadad S and Deka P C 2016 Offshore wind power resource assessment using Oceansat-2 scatterometer data at a regional scale J. Applied Energy 176 157–170

[18] International renewable Energy Agency (2016) IRENA floating foundations: a game changer for offshore wind power. A supplement to innovation outlook: offshore wind. 5-6

[19] Oh K, Kim J, Lee J, Ryu M and Lee J 2012 An assessment of wind energy potential at the demonstration offshore wind farm in Korea J. Energy 46 555-563

[20] Adaramola M, Agelin-Chaab M, and Paul S S 2014 Assessment of wind power generation along the coast of Ghana J. Energy Conversion and Management 77 61–69

[21] Michael J D, Cristina L A and Mark Z J 2010 California offshore wind energy potential. J. Renewable Energy 35 1244–1254

[22] Ahmmad M R 2014 Statistical Analysis of the Wind Resources at the Importance for Energy Production in Bangladesh. International Journal of Energy, Science and Technology 7 (2) 127-136 http://dx.doi.org/10.14257/ijunesst.2014.7.2.12

[23] Lima D K S, Leao R P S, Santos A C S, Melo F D C, Couto V M, Noronha A W T and Oliveira-Jr D S 2015 Estimating the offshore wind resources of the State of Ceara in Brazil. J. Renewable Energy 83 203-221

[24] Satir M, Murphy F and McDonnell K 2017 Feasibility study of an offshore wind farm in the Aegean Sea, Turkey Renewable and Sustainable Energy reviews 34 243-453 http://dx.doi.org/10.1016/j.rser.2017.06.063

[25] Monfared M, Rastegar H and Kojabadi H M 2009 A new strategy for wind speed forecasting using artificial intelligent methods J. Renewable Energy 34 845–848

[26] Li G and Shi J 2010 On comparing three artificial neural networks for wind speed forecasting J. Applied Energy 87 2313–2320

[27] Garlapati N, Ravi S R, Natansh K N, Surendra S K and Vimal S 2016 Application of OSCAT satellite data for offshore wind power potential assessment of India. 5th International Conference on Advances in Energy Research, ICAER 2015, 15-17 December 2015, Mumbai, India. Energy Procedia 90 89 – 98

[28] Ulazia A, Saenz J and Ibarra-Berastegui G 2016 Sensitivity to the use of 3DVAR data assimilation in a mesoscale model for estimating offshore wind energy potential. A case study of the Iberian northern coastline. Applied Energy 180 617–627

[29] Zheng C W, Li C Y, Pan J, Liu M Y and Xia L L 2016 An overview of global ocean wind energy resource evaluations Renewable and Sustainable Energy Reviews 53 1240–1251

[30] Gadad S and Deka P C 2016 Offshore wind power resource assessment using Oceansat-2 scatterometer data at a regional scale Applied Energy 176 157–170

[31] Nagababu G, Kachwaha S S and Savsani V 2017 Estimation of technical and economic potential of offshore wind along the coast of India J. Energy 138 79-91

[32] Amirinia G, Mafi S and Mazaheri S 2017 Offshore wind resource assessment of Persian Gulf using uncertainty analysis and GIS Renewable Energy 113 915-929

[33] Carvalho D, Rocha A, Gomez-Gesteteira M and Santos S C 2017 Offshore winds and wind energy production estimates derived from ASCAT, OSCAT, numerical weather prediction
models and buoys - A comparative study for the Iberian Peninsula Atlantic coast. *J. Renewable Energy* 102 433-444

[39] Schallenberg-Rodríguez J and Montesdeoca N G 2018 Spatial planning to estimate the offshore wind energy potential in coastal regions and islands. Practical case: The Canary Islands. *Energy* 143 91-103

[40] Kusia A and Song Z 2010 Design of wind farm layout for maximum wind energy capture. *Renewable Energy* 35 685–694

[41] Barthelmie R I and Jensen L E 2010 Evaluation of wind farm efficiency and wind turbine wakes at the Nysted offshore wind farm. *J. Wind Energy* 13 573–586

[42] Gaumont M, Réthoré P E, Bechmann A, Ott S, Larsen G C and Pena D A 2012 Benchmarking of wind turbine wake models in large offshore windfarms. In: Proceedings of the science of making torque from wind 34 1-9

[43] Seim F 2015 Validating kinematic wake models in complex terrain using CFD (Master thesis). Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences. Akershus, Norway.

[44] Jeon B K and Huh J 2015 Comparison and verification of wake models in an onshore wind farm considering single wake condition of the 2 MW wind turbine. *J. Energy* 38 1769–1777

[45] Niayifar A and Porte-Angel F 2016 Analytical Modeling of Wind Farms: A New Approach for Power Prediction. *J. Energies* 9 1-13

[46] Hou P, Hu W, Soltani M, Chen C and Chen Z 2017 Combined optimization for offshore wind turbine micro siting. *J. Applied Energy* 189 271–282

[47] Attias K and Ladany S P 2011 Optimal Layout for Wind Turbine Farms. Proceedings World renewable energy Congress, 8-13 May 2011, Linkoping, sweden

[48] Gao X, Yang H and Lu L 2014 Study on offshore wind power potential and wind farm optimization in Hong Kong. *J. Applied Energy* 130 519–531 http://dx.doi.org/10.1016/j.apenergy.2014.02.070

[49] Shakoor R, Hassan M Y, Raheem A and Wu Y 2016 Wake effect modeling: A review of wind farm layout optimization using Jensen’s model. *Renewable and Sustainable Energy Reviews* 58 1048–1059. http://dx.doi.org/10.1016/j.rser.2015.12.229

[50] Ajit C P, John C, Mahdi K, Sami B and Lars J 2017 Application of an offshore wind farm layout optimization methodology at Middelgrunden wind farm. *J. Ocean Engineering* 139 287-297

[51] Ou L, Xu W, Yue Q, Ma C L, Teng X and Dong Y E 2017 Offshore wind zoning in China: Method and experience. *J. Ocean & Coastal Management* 10 1-10

[52] Amaral L and Castro R 2017 Offshore wind farm layout optimization regarding wake effects and electrical losses. *Engineering Applications of Artificial Intelligence* 60 26–34 http://dx.doi.org/10.1016/j.engappai.2017.01.010

[53] Green R and Vasilakos N 2011 The economics of offshore wind. *J. Energy Policy* 39 496–502

[54] Iris F A and Evrim U 2016 Assessment approaches to logistics for offshore wind energy installation. *J. Sustainable Energy Technologies and Assessments* 14 80–91

[55] He Z, Xu S, Shen W, Zhang H, Long R, Yang H and Chen H 2016 Review of factors affecting China’s offshore wind power industry. *Renewable and Sustainable Energy Reviews* 56 1372–1386

[56] Colmenar-Santos A, Perera-Perez J, Borge-Diez D and DePalacio-Rodriguez C 2016 Offshore wind energy: A review of the current status, challenges and future development in Spain. *J. Renewable and Sustainable Energy Reviews* 64 1–18

[57] Sarkar B R and Faiz T I 2017 Minimizing transportation and installation costs for turbines in offshore wind farms. *J. Renewable Energy* 101 667-679

[58] Katsaparakakis D A and Christakis D G 2014 Seawater pumped storage systems and offshore wind parks in islands with low onshore wind potential. A fundamental case study. *J. Energy* 66 470-486. http://dx.doi.org/10.1016/j.energy.2014.01.021

[59] Michailides C, Goa Z and Moan T 2016 Experimental and numerical study of the response of the offshore combined wind/wave energy concept SFC in extreme environmental conditions. *J. Marine Structures* 50 35-54
[60] Tsai Y, Huang Y and Yang J 2016 Strategies for the development of offshore wind technology for far-east countries – A point of view from patent analysis J. Renewable and Sustainable Energy Reviews 60 182–194 http://dx.doi.org/10.1016/j.rser.2016.01.102

[61] Qin C, Saunders G and Loth E 2017 Offshore wind energy storage concept for cost-of-rated-power savings J. Applied Energy 201 148–157

[62] Ajayi O O, Fagbenle, R O and Katende J 2011 Assessment of Wind Power Potential and Wind Electricity Generation Using WECS of Two Sites in South West, Nigeria. International Journal of Energy Science 1 (2) 78-9

[63] Ohunakin S O 2011 Assessment of wind energy resources for electricity generation using WECS in North-Central region, Nigeria J. Renewable and Sustainable Energy Reviews 15 1968–1976

[64] Adaramola M S, Paul S S and Oyedepo S O 2011 Assessment of electricity generation and energy cost of wind energy conversion systems in north-central Nigeria J. Energy Conversion and Management 52 3363-3368.

[65] Oyedepo S O, Adaramola M S and Paul S S 2012 Analysis of wind speed data and wind energy potential in three selected locations in south-east Nigeria. International Journal of Energy and Environmental Engineering, 3 (7) 1-11

[66] Ajayi O O, Ohijeagbon O D, Ogbonnaya M and Attabo A 2016 Wind power mapping and NPV of Embedded generation systems in Nigeria. International Journal of Environmental, chemical, Ecological, Geological and Geophysical Engineering 10 (5) 394-405

[67] Ajayi O O, Fagbenle R O, Katende J, Ndambuki J M, Omole D O and Badejo A A 2014 Wind Energy Study and Energy Cost of Wind Electricity Generation in Nigeria: Past and Recent Results and a Case Study for South West Nigeria J. Energies 7 8508-8534.

[68] Abdulkarim A, Abdelkader S M and Morrow D J, Falade A J and Adediran Y A 2017 Statistical analysis of wind speed for electrical power generation in some selected sites in northern Nigeria Nigerian Journal of Technology, 34 (4) 1249-1257

[69] Fatigun A T, Akoshile C O, Ajibola T B, Salau R O, Faweya E B, Aduloju K A and Oyedele E A 2017 Evaluation of Wind Energy Potential of Ikeja, Southwest, Nigeria using Two-Parameter Weibull Distribution Function J. of Engineering 7(09) 2278-2289