*Available online www.jsaer.com*

***Journal of Scientific and Engineering Research*, 2020, 7(7):109-121**

**Research Article**

**ISSN: 2394-2630**
**CODEN(USA): JSERBR**

# Application of Small Scale Wind Turbine for Distributed Electricity Supply and Irrigation Farming: A Case Study of Opanda Farm Settlement in Enugu State, Nigeria

**Chidiebere Diyoke*[1], Ugwu Kenneth C[2]**

[1]Department of Mechanical Engineering, Enugu State University of Science and Technology (ESUT), Nigeria
[2]Department of Agricultural and Bioresource Engineering, Enugu State University of Science and Technology (ESUT), Nigeria
*Correspondence: Chidiebere.diyoke@esut.edu.ng;diokec@yahoo.co.uk

**Abstract** Mechanised agriculture has the potential to supply Nigeria with the export needs, it requires to diversify and close its GDP gap. This potentials can be actualised if the rural agricultural farmers adopted the use of mechanised irrigation farming techniques.

Wind is widespread in Nigeria and wind powered irrigation system is a clean and decentralised alternative for providing rural communities with electricity for meeting domestic and irrigation farming power needs in a sustainable way.

In this study, the technical, financial and economic viability of supplying 10 hectares of land with irrigation water for rice farming over two seasons using 10, 30 and 55 kW wind turbine powered irrigation pumping system, with Ada-Rice in Opanda, Enugu State Nigeria as a case study. First, four different kind of basin irrigation options were designed and irrigation water demand estimated for each option. Then the wind powered system was sized based on the head of water and horsepower (HP) required to abstract and supply irrigation water demand The cost of the three different wind turbines and four irrigation schemes were calculated and compared using the economic and financial net present value (NPV) as metrics.

It was found that the wind turbines can supply the irrigation water requirement of paddy rice in the study area. The economic analysis result showed that all the analysed wind turbines has economic benefits in the studied location but none is financially viable from the commercial financial investment perspective except over 70% subsidy is given on total investment cost. The 10 kW is the most suitable, in terms of NPV and capacity factor in the study location.

**Keywords** Wind Power, Irrigation, Distributed Generation, Weibull, Power Density

## 1. Introduction

In the last decade, global warming and other pollution from fossil-based generation plants is impacting energy policy over the world [1]. Electrical energy networks and the methods by which electrical energy is generated are also changing. Among the committee of advanced nations, interest is now shifting from grid connected fossil based generation to renewable based distributed generation (DG) for meeting the energy needs especially that of the dispersed and isolated local communities [2,3]

Among the range of DG technologies such as fuels cells, geothermal systems, small steam turbines, reciprocating engines, combined heat and power (CHP), micro-turbine and renewables (solar systems, hydro and wind turbine) [2]; renewable based generation technologies are seen as the golden bullet to help in solving the world energy challenges especially that of dispersed communities[2]. The benefits derivable from shifting from grid centralised fossil generation to decentralised renewable based generation are enormous. Rural and isolated villages where grid extension are not economically feasible can be electrified through locally available renewable energy sources to meet their electrification. The benefits of this approach include: (1) Energy security through a clean and reliable energy supply (2) Increased availability and reliability of energy supply (3) Cheap energy and (5) Improvement in agricultural productivity

Nigeria government is making tremendous effort to improve the quality and duration of power supply while cutting back on emissions of carbon dioxide. One of such efforts is the setting up of an ambitious renewable energy (RE) policy target to increase the share of renewable electricity generation in Nigeria generation mix in the total power sector by 18 and 20 percent by the year 2020 and 2030 respectively. Figure1 gives a breakdown of the incremental additions proposed [4].

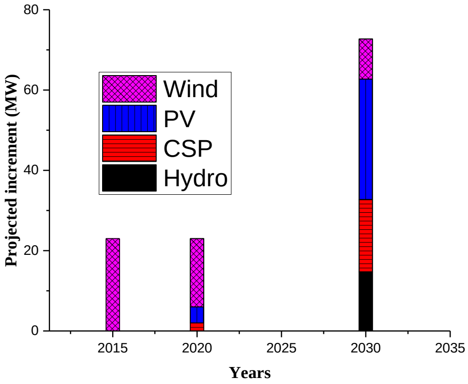


***Figure 1:*** *Yearly total projected renewable energy deployment by resource [4]*

Nigeria is an oil dependent economy and needs to diversify its economy to grow. Mechanised agriculture has the potential to supply Nigeria with the export needs, it requires to diversify and close its GDP gap. This potentials can only be actualised if the rural agricultural settlements/villages where this agricultural activities take place are electrified and the farmers use mechanised farming techniques. Wind is widespread in Nigeria and can provide these rural communities with electricity for meeting both domestic and irrigation farming power needs in a sustainable way.

However the lack of sound technical information on the potential and economic viability of wind electricity militates against the investment in this sector. Hence, the aim of this paper is to assess the technical and economic viability of deploying wind turbine irrigation water pumping system (WT-IWP system) in a Nigerian rural farm settlement for the twin solution of meeting irrigation and electrical power needs. This will help the government and interested investors in decision making

### 1.1. Previous studies on wind energy utilisation in Nigeria

A lot of research has been carried out by so many scholars' on small and medium wind turbines (WTs) Adaramola and Oyewola [5] carried out a study on wind speed pattern and energy potential in Nigeria and concluded that there is potential for wind energy utilization in Nigeria. In another research, Odo *et al* [6] studied the potentials of wind availability at selected heights above the ground in Enugu, Onitsha and Owerri based on meteorological data of annual average values of wind speed obtained over a twenty five years period and concluded that there are exploitable wind energy in the studied locations. A similar research by Oyedepo *et al.* [7] for the same location on wind speed characteristics and energy potential using Weibull distribution concluded that the annual mean wind speed for Enugu, Owerri and Onitsha are 5.42, 3.36 and 3.59 m/s, respectively. Ohunakin and Akinnawonu [8] carried out an evaluation of the wind energy potential and economics of wind power generation in Jos, Plateau State, Nigeria and concluded that Jos is a very suitable site for wind power applications. Annual values of mean wind speed, average power density and total energy at 10m height for Jos were reported as 8.6 m/s, 458W/m$^2$ and 4013 kWh/m$^2$/year respectively. In another research, Adaramola *et al* [9] investigated the economic viability of adopting wind energy conversion systems (WECS) in eight selected sites in Southwest Nigeria using a 2-parameter Weibull function. They reported that the annual wind speeds varies from 2.12 m/s in Ondo to 4.93 m/s in Lagos while the levelised cost of electricity varies from 0.07 and 0.11 \$/kWh to 2.87 and 4.59 \$/kWh at limit values of turbine specific cost band intervals of 1000 and 1600 \$/kW. The authors concluded that Lagos having the highest accumulated energy outputs of \$3767.68/ MW h/yr. from De-Wind D7 at 70 m hub height is the most preferred economically viable for power generation in terms of the levelised unit cost method.

Outside Nigeria, many of such studies have also been done. Hammad [10] compared the economics of water pumping in Jordan by using different energy sources such as photovoltaic, wind and diesel powered water pumping systems and reported that the cost of using energy sources of wind and photovoltaic is lower than diesel engine based pumping systems. Rehman and Sahin [11]studied the utilization of power of the wind for pumping water for remotely located inhabitants of Saudi Arabia not connected to the national power grid, using Small turbines of 1–10 kW and reported that wind power pumping system is viable both technically and economically at the studied locations. Some other studies have also shown the competitiveness of RE sources of power when electricity is shared with agricultural cultivation. The options available range from direct pumping using wind turbines, photovoltaic panels, or hybrid of both [11].

### 1.2. Novelty of the research

As can be seen from the reviewed works, many wind research work done for Nigeria have centred only on wind measurements and wind power resource assessment and characteristics using the Weibull distribution. However to the best of the author’s knowledge, technical analysis of application of small to medium capacity wind energy conversion systems (WECS) in solving twin problems of electricity and irrigation water for round the season farming has not been carried out for any site in Enugu Nigeria.

This research therefore fills this gap by focusing on the potential of adopting a small wind energy conversion system (WECs) in Opanda farm settlement of Enugu Nigeria for supplying irrigation power for round the season rice farming. The energy required to implement some designed irrigation system case studies was investigated and the annual electricity that can be generated from a given capacity WECS is predicted. Then the financial and economic viability of the case studies is assessed. The result of the study will aid both some interested group of farmers, government and any other interested party in making informed technical, economic and financial policy decisions regarding investments in wind energy conversion system in the analysed area.

## 2. Research Methodology

The research methodology consists of three key steps: Selection of study area, mathematical modelling and economic analysis.

### 2.1. The case study area

Opanda is selected as a case study for this research because it is a representative case of a rural agricultural location without a centralised irrigation scheme. The agricultural settlement is located in Uzo Uwani local government area of Enugu, Nigeria with geographical coordinates 6.48°North and 7.6° East and flat topography. It is bordering Kogi state and Anambra state. The agricultural town hosts many agricultural settlement camps chief among them are Ada rice and Game reserve. The reserve, has a land mass of about 232.98 square kilometres and shares a boundary with Bassa as well as Dekina local government area of Kogi state [12]. The monthly wind speed data of the site was obtained from [6]. These values refer to 25 years daily averages of wind speed data at 10 m meteorological height and 1.225kg/m$^3$ air density obtained from the data bank of Nigerian Meteorological Agency (NIMET). The average wind speed of the site is estimated as 5.5 m/s at anemometer height of 10m [7].

### 2.2.Modelling the WT-IWP system

The simulation of the wind turbine water pumping irrigation system (WT-WPIS) system needs the models of the wind turbine (WT), water pump, Irrigation crop water demand (peak and seasonal) as shown in Figure 2. The Wind turbine model calculates the conversion of wind speeds to power. The pump model estimates the power required by the pump to supply the calculated irrigation water demand. The irrigation model is used to assess the seasonal and peak crop water requirements both for designing the power of pump and energy required by the system.

An Agricultural rural location with a land area of 10 ha was used for the study. Four different kind of irrigation schemes were designed. Then using historical climate data for paddy rice grown in the region, the peak and seasonal irrigation water demand, required to plant paddy rice for two seasons was estimated for each irrigation scheme. Then the head of water and power required to abstract and supply the calculated irrigation water demand was then determined in order to determine energy to be supplied by the wind electric powered irrigation systems. The difference between the power generated by the WES and the energy requirements of the various irrigation systems represents the energy sold feedback to the grid. The profitability and economic impact of the various designed irrigation systems was checked by estimating the financial and economic net present value (NPV)[13] of the irrigation optioned considered. The following sections summarises the calculation procedure adopted.

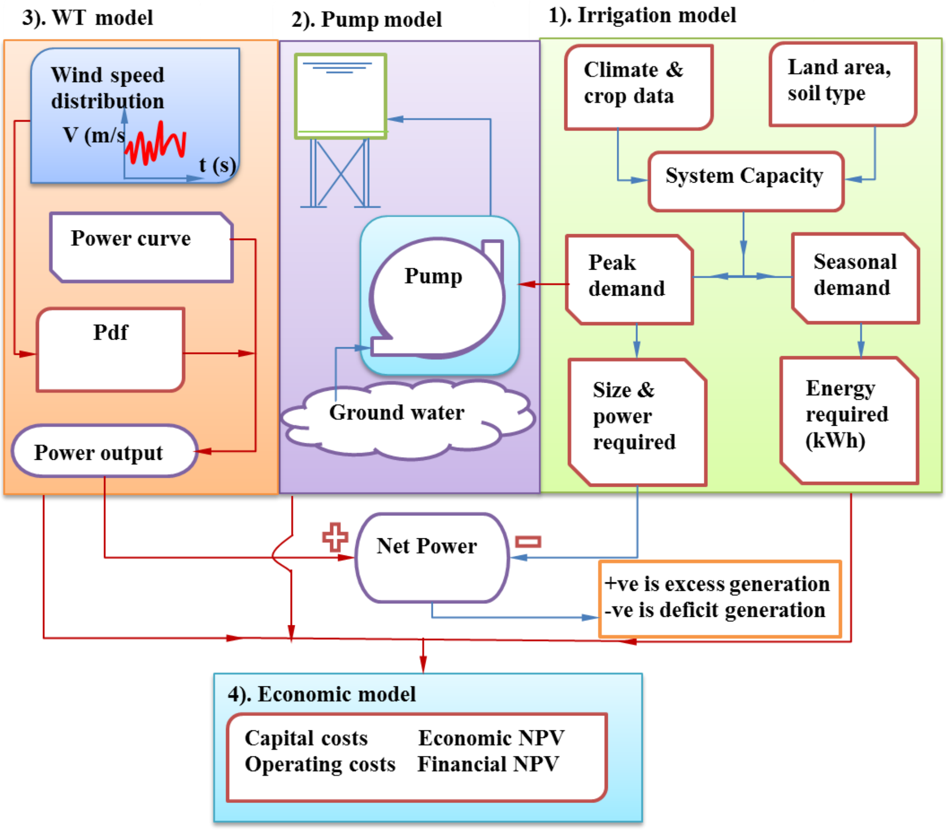


*Figure 2: Flowchart of the methodology used to analyse the potential of wind in meeting rural energy needs of irrigation and electricity*

### 2.2.1. Irrigation model

The first steps in designing an irrigation system involves selecting the type of irrigation, its requirements and estimating water demand.

Irrigation systems differ in their pumping energy and water requirement. The selection of the most suitable system whether drip, sprinkler or surface depends on several factors among which are the type of crop, the climate of application, the technical knowhow of the intending user, flow rate of water required, system cost, availability of equipment locally, maintenance and repair services and availability of spare parts. Basin irrigation method is selected for application here because it is cheap, can be used for all types of crops and it requires no complex equipment and skilled labour [14].

Two important irrigation design drivers are[14]:

- The peak scheme water demand (PSWD) which is the discharge essential to meet the maximum crop water requirements, plus the losses that occur in field application and the distribution system
- The seasonal water demand (SWD) which is the volume of water needed over the growing season, taking into account the water losses in the distribution system and in field application.

Estimating the water requirement at the peak stage in the crop growth cycle makes it possible for all the components of the irrigation system to be optimized for chosen application. This water requirement depends on type of plant, soil type and meteorology, evapotranspiration rates, stage of crop growth, the geometric layout of the available land and required crop spacing.

The PSWD is estimated using the following:

$$\mathrm{PSWD}\ \left({}^{\mathrm{m}^3}\!/_{\mathrm{s}}\right) = \frac{\mathrm{PCWR}\ \times \mathrm{A} \times 24}{\text{hours of operation}} \tag{1}$$

Where PCWR is the peak crop water requirement ($m^3$/s/ha) and A is cropped area in hectares.

The SWD in depth of water (d) per plant per day is estimated as follows:

$$\mathrm{SWD} = \frac{\mathrm{A(ha)} \times 10\mathrm{d}}{\mathrm{e}} \quad (\mathrm{m}^3) \tag{2}$$

Where e is the overall scheme irrigation efficiency, which is the product of the conveyance efficiency ($e_c$) and the field application efficiency ($e_a$).

To calculate PCWR where detailed experimental data on a crop is not available, FAO recommended seasonal crop water irrigation application depth (d) of 800-1500 mm for paddy rice for one planting season (120 days) [15]. Based on the indicative values of water needs of paddy rice, four irrigation options for planting paddy rice on a land area of 10 hectares for two seasons in a year were generated for analysis, using PCWR of 1.5 l/s/ha and application depth values of 800, 1000, 1200, and 1500mm respectively. Table 1 shows the design irrigation options and their parameters. It is assumed the irrigation options will operate continuously for 10 hours every day of the month except the peak rainy season months of May –July.

**Table 1:** Analysed irrigation options

| **Irrigation Schemes** | **I** | **II** | **III** | **IV** |
|---|---|---|---|---|
| Actual Hectares Irrigated | 10 | 10 | 10 | 10 |
| Conveyance efficiency (%) | 100 | 95 | 90 | 80 |
| Application efficiency (%) | 100 | 60 | 55 | 55 |
| Total dynamic head | 20 | 25 | 30 | 35 |

### 2.2.2. Pump model

A complete irrigation system consists mainly of a water source and water lifting mechanism and its prime-mover and energy supply [15]. The source of water for the irrigation scheme considered here is a nearby river and water will be pumped using a centrifugal pump powered by some part of the electricity produced by the wind turbine. The overall power required to pump water is a function of both the apparent vertical height lifted and the flow rate at which water is lifted. The overall power demand by the pump is calculated as follows:

$$\mathrm{P_{in}} = \frac{\mathrm{PSWD} \times \rho \mathrm{gH}}{1000 \times \eta_m \times \eta_p} (\mathrm{kW}) \tag{3}$$

The design operating mass flow(PSWD) corresponding to the operational total head (H) can be calculated from the standard characteristic pump curve according to the following equation:

$$PSWD = \mathrm{PSWD}_r \sqrt{\frac{\mathrm{H}}{\mathrm{H}_r}} \tag{4}$$

Where, $\mathrm{PSWD}_r$ is the reference water flow at the reference hydraulic head $\mathrm{H}_r$ obtained from the standard characteristic curve of the pump, H, is the total head or the equivalent height that irrigation water is to be pumped, in m , $\eta_p$ is pump efficiency, $\eta_m$ is motor efficiency and $\rho$ is density of water in kg/$\mathrm{m}^3$

The total head H, for the system is the sum of static head, operating pressure, friction head $\mathrm{H_f}$ and velocity head, $\mathrm{H_v}$

$$\mathrm{H} = \mathrm{H_s} + \mathrm{H_p} + \mathrm{H_f} + \mathrm{H_v} \tag{5}$$

The total head assumed for the irrigation options I – IV are 20, 25, 30 and 35 m respectively. Friction and velocity head were neglected.

The seasonal overall energy required (SED) to pump the SWD ($m^3$) at the desired head (H) allowing for the efficiency of the pumping plant is calculated as follows:

$$\mathrm{SED\ (kWh)} = \frac{\mathrm{SWD} \times \mathrm{H}}{367 \times \eta_m \times \eta_p} \tag{6}$$

The pumping duration depends on the discharge Q, the required irrigation depth (mm) and the size of the field to be irrigated (ha) [16]. The following formula was used to determine the daily pumping hours (t):

$$\mathrm{t\ (hrs)} = \frac{\mathrm{SED\ (kWh)}}{\mathrm{P_{in}\ (kW)} \times \mathrm{crop\ duration(days)}} \tag{7}$$

### 2.2.3. Wind turbine model

The wind turbine convert wind speeds into electricity. Taking the wind speed variability into consideration, daily power production from the wind turbine is estimated as follows[17]:

$$\mathrm{P_{WT}} = \int_0^{t=24} \mathrm{P_{WT}}(v,t)\, f(v,t)dt = \sum_i f_i(v) \mathrm{P}_{\mathrm{WT},i}(v) \tag{8}$$

Where $f_i(v)$ is the probability of duration at speed v from Pdf

$P_i(v)$ is the power production from the turbine at speed v from its power curve at time i (kW).

Energy produced annually from the wind turbine system ($\mathrm{YEP_{WT}}$) for a specific site was estimated as follows:

$$\mathrm{YEP_{WT}} = 24 \times 365\ \mathrm{P_{WT}} \tag{9}$$

There are a good number of Pdf models like the Weibull, Rayleigh and Lognormal functions, which can be used to describe the wind speed variation for the site[18]. However Weibull Pdf was used in this research because it is the widely used owing to its ease of use.

The Weibull Pdf of wind is expressed as follows:

$$f(v) = \frac{k}{c}\left(\frac{v_i}{c}\right)^{k-1} e^{-(v_i/c)^k} \qquad 0 \leq v < \infty \tag{10}$$

Where f(v) is the probability of wind speed (v), c is is a scale parameter which has the dimension of velocity and k is a shape factor k and c define the shape of the distribution. They are determined using the following equations respectively:

$$k_{\mathrm{Weibul}} = \left(\frac{\sigma}{v}\right)^{-1.086} \tag{11}$$

$$c_{\mathrm{Weibul}} = \frac{v}{\Gamma\left(\frac{1}{k} + 1\right)} \tag{12}$$

Where $v, \sigma$ is the mean and standard deviation of the wind speed at the site and $\Gamma$ is gamma function

The wind speed at the reference hub height ($v_r$) was converted to the equivalent speed (v) at the wind turbine hub height (h) using the power law expression as follows [18]:

$$\frac{v}{v_r} = \left(\frac{h}{h_r}\right)^{\alpha} \tag{13}$$

Where α is the wind power exponent or shear coefficient that is dependent upon the stability of the atmosphere. This component can be calculated using the following:

$$\alpha = \frac{\ln v - \ln v_r}{\ln h - \ln h_r} \tag{14}$$

α is sometimes taken to be approximately 1/7, or 0.143 for neutral stability conditions, [19], it is however a conservative estimate [20]. Many site specific studies have converged that the coefficient could actually be greater with the consequence of underestimation of the energy resource available [20,21]. Thus α was estimated using the following [7].

$$\alpha = \frac{0.37 - 0.088 \ln v_r}{1 - 0.088 \ln(h_r/10)} \tag{15}$$

Three candidate turbines of capacity, 10, 30, and 50kW, were selected for analysis in this work. Technical information of the chosen wind turbines were obtained from [22,23] and summarised in the Table 2.

### 2.3. Economic analysis

The economic evaluation of the proposed system was evaluated using the financial Net Present Value (NPV) approach as follows [24, 25]:

$$NPV = -I_0 + \sum_{t=0}^{t} \frac{CF_t}{(1+i)^t} \tag{16}$$

Where $I_0$ denote the capital cost, CF is cash flow, i is interest rate and t time is years

**Table 2:** WT technical parameters

| Turbine parameters | Alize 10 kW | Pitch wind 30 kW | Nordtank 55 kW |
|---|---|---|---|
| Type | HAWT | HAWT | HAWT |
| Rated power (kW) | 10 | 30 | 55 |
| Rotor diameter (m) | 7 | 14 | 15 |
| Rotor area (m$^2$) | 38.5 | 154 | 176.7 |
| Hub height (m) | 18-36 | 20/62 | 22 |
| Rotor peak $\boldsymbol{C_p}$ | | | |
| Availability (%) | | | |
| Rated speed (m/s) | 12 | 15 | - |
| Cut in speed (m/s) | 3 | 2 | 3 |
| Cut out speed (m/s) | none | none | 25 |
| Gear box type | Gearless | none | Gearles |
| Max RPM | 300 | 81 | |

The pump cost may be calculated as follows**:**

$$c_p = P_{in} t c_e \tag{17}$$

Where t and $c_e$ denote total annual pumping hours [hours] and unit cost of electrical energy respectively

The Summary of Input parameters for NPV calculation are as follows:

- Total investment cost for the 10, 30 and 55 kW is $54,461, $142,991 and $197,781[26,27]of which 70% is obtained through a loan at interest rate of 22% for 10 years.
- Investment cost for storage tank and irrigation technology is $4,354 and 218 $/ha respectively.
- Salvage values of 10% of investment cost is assumed while depreciation is 10 years straight line method.
- Fixed and variable O&M cost of 56 $/kWh-Yr. and 5.17 $/kWh-Yr is used [28].
- Combined federal and state income tax rate, of 15%, inflation rate of 3%, weighed average cost of capital of 14.59% for 10kW and 15.96% for 30 and 55 kW respectively.
- Average Cost of Electricity is0.17 $/kWh while feed in tariff rate is 0.15 $/kWh

## 3. Results and discussion

### 3.1. Energy requirements and production

The calculated pumping hours, irrigation peak power demand and the annual electrical energy required in kWh to irrigate paddy rice for two plantings seasons in a year is as shown in Table 3. The energy supplied by the WT system is used to meet the energy demand of the irrigation pumping system. As can be seen from table 3, the annual energy demand of the various irrigation schemes (1-IV) varies according to the water requirement. Irrigation scheme IV required the highest annual energy of about 93 MWh while scheme I has the lowest annual energy need of about 13 MWh for the considered 10 ha under the design conditions.

**Table 3:** Pump Energy requirements for Rice Farming on 10 Hectares

| | **Irrigation Schemes for 10 Hectares** | | | |
|---|---|---|---|---|
| | **I** | **II** | **III** | **IV** |
| Scheme water demand | | | | |
| - Peak Discharge ($\mathbf{m^3/s}$) | 0.036 | 0.063 | 0.073 | 0.082 |
| - Volume ($\boldsymbol{m^3}$) | 160,000 | 421,053 | 525,253 | 681,818 |
| Pumping time (hours) | 10.29 | 15.43 | 16.71 | 19.29 |
| Peak power demand (kW) | 10.09 | 22.13 | 30.58 | 40.13 |
| Total Dynamic Head (m) | 20 | 25 | 30 | 35 |
| Annual energy demand (kWh) | **12,456** | **40,974** | **61,337** | **92,891** |

Figure 3 shows the output power plot for the three investigated turbine capacities of 10, 30 and 55 kW using k value of 1.8

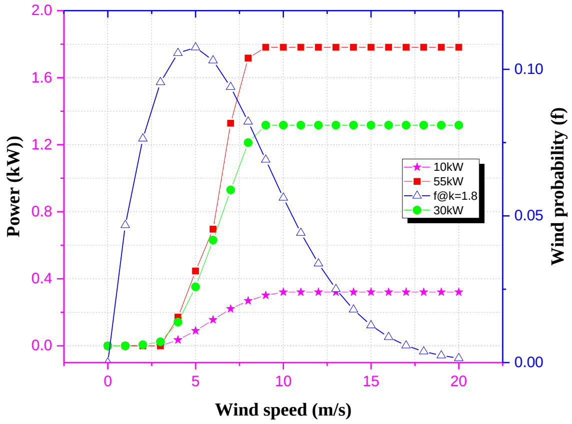


*Figure 3: output power and average velocity for the study location*

Average power output ratings in kWh of the three wind energy systems (WES) of 10, 30, 55 kW at a height of 30 m were determined as 2.64, 9.68 and 14.46 kWh respectively as shown in Table 4. Yearly energy production (YEP)of WTs varies with hub height and capacity factor (CF). YEP and CF corresponding to the investigated turbine capacities at hub heights of 30and 50 m respectively are summarized in Table 4. The 10kW turbine YEP increased by 16.9% to about 27.10 MWh when the hub height increased from 30 to 50m while that for the 30 and 50 kW systems increased by 14.1 and 17.0% to 96.7 and 148.2 MWh respectively. While high wind velocity at the increased hub height accounted for the increase in YEP with hub height, the 55 kW system recorded more increase in YEP at the same hub height than the 10 and 30 kW system because it has bigger diameter, which means more of the high wind velocity is converted into power. Since the turbines do not have the same rotor diameter, it is necessary to have a fair comparison of their outputs. A useful figure of merit for the analysis is the annual energy yield produced per rotor swept area. As can be observed (Table 4)the 55 kW system is the best in terms of energy output per rotor area for the studied location at the hub heights of 30 and 50m.

**Table 4:** Summary of results of Energy Output and capacity factor for 10, 30 and 50kw WES

| **Parameters** | **Hub Height (m)** | | | | | |
|---|---|---|---|---|---|---|
| | **10kW** | | **30kW** | | **55 kW** | |
| | **30m** | **50m** | **30m** | **50m** | **30m** | **50m** |
| Average power output (kWh) | 2.64 | 3.09 | 9.68 | 11.04 | 14.46 | 16.92 |
| Daily energy output (kWh) | 63.5 | 74.2 | 232.2 | 265.0 | 347.1 | 406.1 |
| YEP at maximum capacity (kWh) | 23,165 | 27,091 | 84,770 | 96,736 | 126,690 | 148,244 |
| YEP per Rotor Area (kWh/$m^2$) | 601.7 | 703.7 | 550.5 | 628.2 | 717.0 | 839.0 |
| Average monthly output energy (kWh) | 1,930 | 2,258 | 7,064 | 8,061 | 10,558 | 12,354 |
| Capacity Factor (%) | 26 | 31 | 16 | 37 | 26 | 31 |

The superimposed monthly profile graph of the monthly irrigation energy requirement of the four irrigation options and the monthly energy generated by the WES is as shown in Figure 4. As can be observed, there are months when the energy of the WES is not enough to meet the irrigation energy demand.

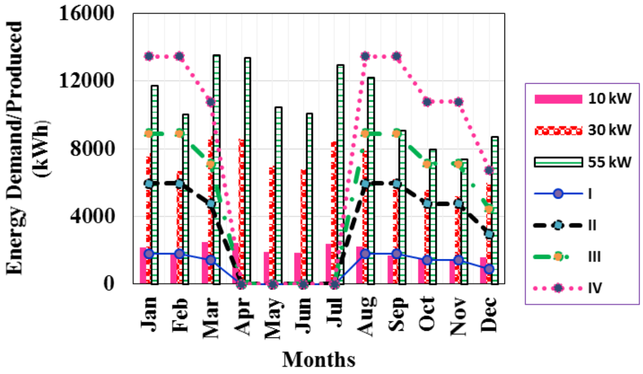
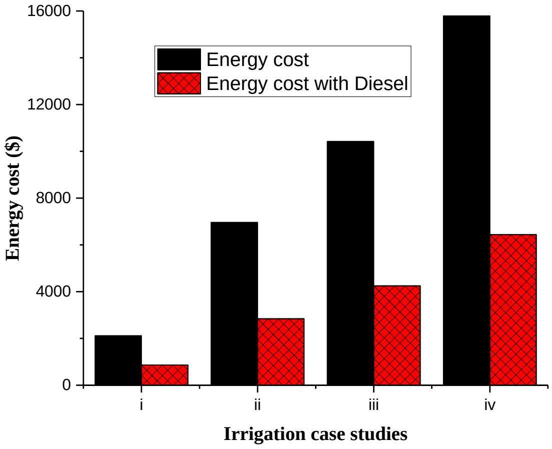


*Figure 4: Monthly energy demand of the irrigation system and energy generated by the wind turbine (kWh)*

This is due to variation in wind speed and irrigation energy demand round the season. Peak energy requirement for paddy rice occurs at the August break and dry season months (Jan and Feb, Sept) when there is no rainfall. In the months of April to July, the irrigation energy requirement is zero because it is the peak of rainy season period when no irrigation energy is needed to be supplied. To improve the mismatch between the wind systems and irrigation energy requirement, a diesel generator could be used as a backup power. The diesel generator will be used to supply the energy needs of the crop when wind velocity is below cut in velocity of the turbine. Figure 5 shows a comparison of the energy cost of using diesel generator against wind turbine system. Expectedly, the cost of generation using the wind energy system is lower.



F*igure 5: Comparison of energy cost using WES against using diesel generator*

### 3.2. Revenue from excess generation

The Excess electricity generated by the WES is sold back to the grid at the feed in tariff rate of 0.15$/kWh. At the rainy season months of April to Jul, all of the required irrigation energy which would have been met by electricity generated by the wind turbines is available for sale and this will greatly improve the profitability of the farm. The revenue generated by the farmer is the sum of the money saved by not paying for electricity at the rate of 0.17 $/kWh charged by electricity utility plus the revenue from any excess energy feed back to the grid at the feed in tariff rate. The Annual excess kWh generated which is kWh greater than annual kWh required for irrigation is shown in table 5. while Table 6 summaries the results of the annual energy costs savings by the farmer generating his own electricity for irrigation rather than buying at $0.17/kWh plus the annual dollar generated by selling excess capacity at a feed in tariff of 0.15 $/kWh

**Table 5:** Excess (Deficit)Annual kWh generated by the systems

| **Irrigation** | **Excess electricity generated (kWh)** | | |
|---|---|---|---|
| **Schemes** | **10 kW** | **30 kW** | **55 kW** |
| I | 10,709 | 72,313 | 114,234 |
| II | (17,809) | 43,795 | 85,716 |
| III | (38,182) | 23,432 | 65,353 |
| IV | (69,725) | (8,121) | 33,799 |

**Table 6:** Revenue saved from excess capacity and irrigation capacity

| **Irrigation** | **Revenue from Excess Capacity ($)** | | |
|---|---|---|---|
| **Schemes** | **10kW** | **30kW** | **50kW** |
| **I** | 3,724 | 12,965 | 19,253 |
| **II** | 3,398 | 13,535 | 19,823 |
| **III** | 3,398 | 13,942 | 20,230 |
| **IV** | 3,398 | 14,410 | 20,861 |

### 3.3. Cost and financial feasibility summary

The results of the NPV of the three wind turbines considered for the analysed irrigations optioned using both financial feasibility and economic analysis is shown in Figure 6 for the irrigation case study I.

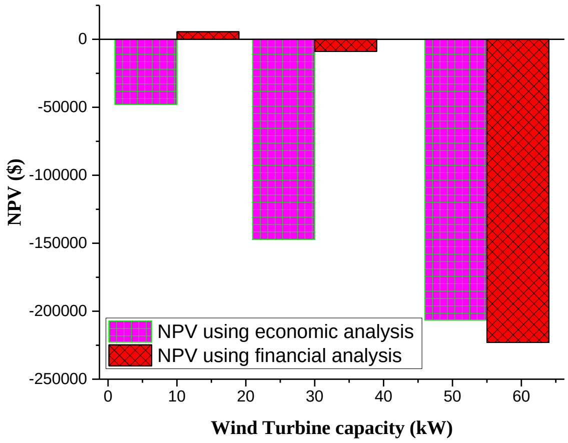
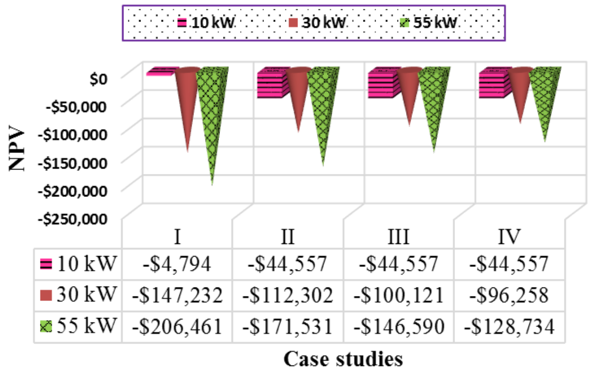


*Figure 6: Economic and Financial NPV of the Wind turbine irrigation System*

It can be seen from the figure that the 10 kW wind system is economically feasible with a positive NPV of $5,634 while the 30 and 55 kW systems are not with a negative NPV of $8,913 and $222,995 respectively. However, from the investor perspective and according to financial feasibility results, all the three systems are not commercially profitable for deployment in the analysed location for meeting the twin solution of irrigation water supply and electricity demand. It is determined that the financial NPV of the 10, 30 and 55 kW systems for irrigation case study I are negative with values of $47,917, $147,232 and $206,461 respectively. This means thatall the three systems cannot generate adequate incremental cash flows to recover its financial costs (capital and recurrent costs) without external support. The financial NPV of the other irrigation case studies (II-IV) using the selected wind turbine capacities of 10, 30 and 55 kW also returned negative financial NPV as can be seen in Figure 7.



| | I | II | III | IV |
|---|---|---|---|---|
| 10 kW | -$4,794 | -$44,557 | -$44,557 | -$44,557 |
| 30 kW | -$147,232 | -$112,302 | -$100,121 | -$96,258 |
| 55 kW | -$206,461 | -$171,531 | -$146,590 | -$128,734 |

*Figure 7: Financial NPV of the Wind turbine irrigation System*

A reduction in the total investment cost of the whole system by over 50% still returns a negative financial NPV but if about 77% of the total investment cost of the whole system is waived or provided in the form of subsidy by Government, the financial profitability of the 10 kW system becomes profitable for case study I with a positive NPV of $330 while that for 30 and 55 kW systems remain negative.

## 4. Conclusions

Renewable energy distribution technologies (RETs)have environmental benefits over fossil energy sources and represents a unique opportunity to do away with the conventional generation from fossil plants which have failed to meet the needs of the poor in isolated and dispersed rural communities.

The potential of using a wind turbine for the twin solution of community lighting and irrigation farming has been analysed in this paper. This kind of system is very suitable for a small scale remote application where round the clock electrical service is not necessary and grid electricity is non-existent.

It was found there is a big economic potential in the investigated location because of the existence in this region of both rivers and underground water potential, and a good wind energy potential. The case study clearly shows that wind turbines for the twin solution of irrigation farming and electricity supply has economic benefits in the studied location but it is not profitable from the commercial financial investment perspective except over 70% subsidy on total investment cost is granted.

Among the three small wind turbine options considered, the 10kW turbine is the most suitable, in terms of cost and energy production for use in the study location.

With the falling prices of small wind turbines, this source of energy must be popularized and integrated in the development strategy of Nigeria to enable wide deployment. To improve the mismatch between wind systems and irrigation energy requirement, a diesel generator could be used as a backup power. The diesel generator will be used to supply the energy needs of the crop when wind velocity is below cut in velocity of the turbine. Also to improve the use efficiency of the energy supply system, the WES should be used round the season and one way of achieving this is by the farmer growing both dry season crop and a wet season crop the same time.

## Acknowledgments and conflict of interest

We would like acknowledge the contribution of anonymous reviewers for their comments and criticisms that helped to improve this paper.

We declare no conflict of interest whatsoever.

## Source of Funding

We received no funding for this research

## References

[1]. Diyoke C, Wu C. Thermodynamic analysis of hybrid adiabatic compressed air energy storage system and biomass gasification storage (A-CAES + BMGS) power system. Fuel 2020;271:117572. doi:https://doi.org/10.1016/j.fuel.2020.117572.

[2]. Diyoke C. Comparative Thermo-Economic and Advanced Exergy Performance Assessment of Wind Energy for Distributed Generation in Four Sites in Nigeria. Int J Renew Energy Dev 2020;9:339–51. doi:10.14710/ijred.9.3.339-351.

[3]. OWENS B. THE RISE OF DISTRIBUTED POWER n.d.

[4]. Nigeria's Vision 2020 economic transformation blueprint n.d.;2015. http://www.nigerianstat.gov.ng/pages/download/62.

[5]. Adaramola MS, Oyewola OM. On wind speed pattern and energy potential in Nigeria. Energy Policy 2011;39:2501–6. doi:http://dx.doi.org/10.1016/j.enpol.2011.02.016.

[6]. Odo FC, Ugbor DO, Ugwuoke PE. Twenty-five years of wind data in south-eastern locations of Nigeria: Modeling and prediction of wind potential . Int J Phys Sci 16AD;8(2),:83–4, 85, 86 87, 88.

[7]. Oyedepo SO, Adaramola MS, Paul SS. Analysis of wind speed data and wind energy potential in three selected locations in south-east Nigeria. 2012.

[8]. Ohunakin OS, Akinnawonu OO. Assessment of wind energy potential and the economics of wind power generation in Jos, Plateau State, Nigeria. Energy Sustain Dev 2012;16:78–83. doi:http://dx.doi.org/10.1016/j.esd.2011.10.004.

[9]. Adaramola MS, Oyewola OM, Ohunakin OS, Dinri RR. Techno-economic evaluation of wind energy in southwest Nigeria' . Front Energy 2012;6(4):366.

[10]. Hammad M. Photovoltaic, wind and diesel: A cost comparative study of water pumping options in Jordan. Energy Policy 1995;23:723–6. doi:http://dx.doi.org/10.1016/0301-4215(95)00032-E.

[11]. Rehman S, Sahin AZ. Wind power utilization for water pumping using small wind turbines in Saudi Arabia: A techno-economical review. Renew Sustain Energy Rev 2012;16:4470–8. doi:http://dx.doi.org/10.1016/j.rser.2012.04.036.

[12]. Bello UA. Opanda Game Reserve: 30 Years of Abandonment . Dly Trust News Pap n.d.

[13]. Diyoke C. A new approximate capacity factor method for matching wind turbines to a site: case study of Humber region, UK. Int J Energy Environ Eng 2019;10. doi:10.1007/s40095-019-00320-5.

[14]. Gopal C, Mohanraj M, Chandramohan P, Chandrasekar P. Renewable energy source water pumping systems—A literature review. Renew Sustain Energy Rev 2013;25:351–70. doi:http://dx.doi.org/10.1016/j.rser.2013.04.012.

[15]. Kay M, Hatcho N. Small scale pumped irrigation: Energy and cost-FAO Org. 1992.

[16]. C. Brouwer K. Prins MK and MH. FAO Irrigation Water Management: Training manual No5, Irrigation Methods n.d.

[17]. Diyoke C. A new approximate capacity factor method for matching wind turbines to a site: case study of Humber region, UK. Int J Energy Environ Eng 2019:1–12. doi:10.1007/s40095-019-00320-5.

[18]. Carrillo C, Obando Montaño AF, Cidrás J, Díaz-Dorado E. Review of power curve modelling for wind turbines. Renew Sustain Energy Rev 2013;21:572–81. doi:10.1016/J.RSER.2013.01.012.

[19]. Burton T. Wind energy handbook. 2nd ed. Oxford: Wiley; 2011.

[20]. Vaughn N. Wind Energy: Renewable Energy and Environment "2nd Ed . US: CRC press; 2013.

[21]. Rolland S, Auzane B. The potential of small and medium wind energy in developing countries. 2012.

[22]. Danish Wind Energy Association. Wind Turbine Power Calculator n.d. http://drømstørre.dk/wp-content/wind/miller/windpower web/en/tour/wres/pow/index.htm (accessed August 6, 2019).

[23]. Catalogue of European Urban Wind Turbine Manufacturers n.d. http://www.urbanwind.net/pdf/CATALOGUE_V2.pdf.

[24]. Diyoke C, Aneke M, Wang M, Wu C. Techno-economic analysis of wind power integrated with both compressed air energy storage (CAES) and biomass gasification energy storage (BGES) for power generation. RSC Adv 2018;8:22004–22.

[25]. Ujam AJ, Diyoke C. Economic viability of coal based power generation for Nigeria. Am J Eng Res 2013; 2(11): 14–24.

[26]. EIA. The Cost and Performance of Distributed Wind Turbines, 2010-35 Final Report June 2010 prepared for Office of Integrated Analysis & Forecasting U.S. Energy Information Administration n.d.

[27]. Renewable UK. Small and Medium wind UK Market Report 2012.

[28]. Diyoke C, Idogwu S, Ngwaka UC. An Economic assessment of biomass gasification for rural electrification in Nigeria. Int J Renew Energy Technol Res 2014;3 (1):1–17.