Open Access Research Journal of
Science and Technology
Journals home page: https://oarjst.com/
ISSN: 2782-9960 (Online)

OARJ OPEN ACCESS RESEARCH JOURNALS

(RESEARCH ARTICLE)

Check for updates

Cost analysis for a proposed 20 MW wind farm project in Langtang, plateau state, Nigeria

Stanley A Omenai *

Department of Mechanical Engineering, Georgia Institute of Technology, Atlanta, USA.

Open Access Research Journal of Science and Technology, 2025, 13(01), 069-084

Publication history: Received on 03 January 2024; revised on 15 February 2025; accepted on 18 February 2025

Article DOI: https://doi.org/10.53022/oarjst.2025.13.1.0033

Abstract

This paper presents the results of cost analysis carried out for a proposed Wind Power Project in Langtang, Plateau State, Nigeria.

The Annual Energy Production is computed using the standardized calculation template based on Weibull Probability Distribution developed at the National Renewable Energy Laboratory (NREL).

The wind turbine Capital and operating Costs are estimated using the Wind Turbine Design Cost and Scaling Model developed at the National Renewable Energy Laboratory (NREL) for the WindPACT baseline system.

The Cost of Energy (COE) is estimated using standard excel-based template from the Wind Turbine Design Cost and Scaling Model developed at the National Renewable Energy Laboratory (NREL).

Analysis of turbine performance is carried out based on turbine efficiency and Power Production with windspeed using the Weibull Probability Distribution Function. The implications of varying windspeeds on Turbine efficiency and Power Production are also discussed.

Keywords: Levelized Cost of Energy; Capital Cost; Operating Cost; Probability Distribution Function; Weibull; WindPACT

1. Introduction

The region under evaluation for siting of a wind power generation project is Langtang, Plateau State, Nigeria with a 4 MW daily grid electricity consumption and a 14 MW electricity gap [1].

The proposed wind power generation project aims to provide a healthy amount of steady electric power to Langtang. Considering the current energy gap in the area, as well as projected increase in energy demand in the next few years, a 20 MW project was considered logical and thus selected. A total of 10 units of 2 MW wind turbines is proposed to meet the 20 MW capacity requirement for this project. Due to availability of large wind resource in the proposed farm location, a 3-bladed turbine rotor of radius 22 m and a hub height of 40 m was chosen [2].

Airfoil families based on design by Dan Somers (S818, S825, S826) were selected for the turbine blades and an optimum blade planform that maximizes power generation was selected [2].

Cost analysis for the wind Power Generation Project shall be carried out using the Department of Energy (DOE)/National Renewable Energy Laboratory (NREL) scaling model.

* Corresponding author: Stanley A Omenai

The DOE/NREL scaling model is a spreadsheet-based tool that uses simple scaling relationships to project the cost of wind turbine components and subsystems for different sizes and configurations of components [3]. The model does not handle all potential wind turbine configurations, but rather focuses on configurations that are most common in the commercial industry, i.e., three-bladed, upwind, pitch-controlled, variable-speed wind turbine and its variants. Formulas in the model are quite simple. In most cases, costs are a direct function of rotor diameter, machine rating, tower height, or some combination of these factors.

2. Methodology

We shall carry out cost analysis for the proposed 20 MW Wind Power Project to ascertain its profitability in the following steps.

- Calculate the Annual Energy Production (AEP) using the standardized calculation template based on Weibull Probability Distribution developed at the National Renewable Energy Laboratory (NREL).
- Calculate the wind turbine Capital and operating Costs using the Wind Turbine Design Cost and Scaling Model developed at the National Renewable Energy Laboratory (NREL) for the WindPACT baseline system.
- Calculate the Cost of Energy (COE) using standard excel-based template from the Wind Turbine Design Cost and Scaling Model developed at the National Renewable Energy Laboratory (NREL).
- We shall also carry out analysis of the turbine performance based on turbine efficiency and Power Production with windspeed using the Weibull Probability Distribution Function.

3. Cost Metrics

The cost of power produced by the proposed wind turbine farm shall be determined using the spreadsheet approach, considering the size of the wind turbines involved. The standard spreadsheets were developed at the National Renewable Energy Laboratory (NREL).

3.1. Annual energy production

The Annual Energy Production is computed using the standardized calculation template based on Weibull Probability Distribution developed at the National Renewable Energy Laboratory (NREL).

The following parameters are input into the template:

Table 1 Wind Turbine Parameters

S/n	Parameter	Value	Remarks
1	Anemometer Height	100 m	Obtained from wind map
2	Windspeed at Anemometer Height	12.38 m/s	Obtained from wind map
3	Weibull k-Parameter	2	Recommended from NREL Template
4	Rated Power	2,000 kW	Turbine rating
5	Rotor Diameter	44 m	Rotor diameter based on design
6	Hub Height	40 m	Tower height based on design
7	Altitude	0 m	Location altitude
8	Rotor C_p	0.45	Best C_p value obtained from design
9	Cut-in Windspeed	3 m/s	Selected based on historical data for turbines of similar sizes
10	Cut-out Windspeed	26 m/s	Selected based on historical data for turbines of similar sizes
11	Power Law Shear Exponent	0.143	1/7 Power Law relating hub height and wind speed
12	Conversion Efficiency	0.95	Mechanical to Electrical Energy conversion efficiency – Selected based on historical data for turbines of similar sizes
13	Soiling Losses	3.5%	Selected based on historical data for turbines of similar sizes

14	Array Losses	5%	Selected based on historical data for turbines of similar sizes
15	Availability	98%	Selected based on historical data for turbines of similar sizes

Using these parameters as input, we determine the Annual Energy Production per turbine from our chosen site. The following results are obtained:

Energy capture = 5118.23 MWh/year

Capacity Factor = 29.21%

Energy capture ratio = 60.04%

3.2. Wind turbine capital and operating expenditure

The wind turbine Capital and operating Costs shall be estimated using the Wind Turbine Design Cost and Scaling Model [3] developed at the National Renewable Energy Laboratory (NREL) for the WindPACT baseline system.

The baseline rotor blade is assumed to be composed of 60% fiberglass, 23% vinyl adhesive, 8 % studs, and 9% core material.

The following equations shall be used for the computation of the various parameters using the following definitions:

- R = Radius of Rotor
- D = Diameter of Rotor
- MR = Machine Rating (kW)
- AEP = Annual Energy Production (MWh)
- H = Hub Height (m)
- A = Tower Swept Area (m^2)

3.2.1. Rotor Blades

These are the main rotating elements of a wind turbine directly impinged on by incoming wind.

$$Cost\ per\ blade = \frac{(0.4019R^3 - 955.24) + 2.7445R^{2.5025}}{1 - 0.28}$$

3.2.2. Rotor hub

Made from cast iron, the hub holds the blades in position as they turn.

$$Hub\ Cost = [(0.954 \times 0.1452R^{2.9158}) + 5680.3] \times 4.25$$

3.2.3. Rotor pitch mechanism

This is used to adjust the angle of the blades to make best use of the prevailing wind.

$$Total\ Pitch\ System\ Cost = 2.28 \times (0.2106D^{2.6578})$$

3.2.4. Low speed shaft

The shaft transfers the rotational force of the rotor to the gearbox.

$$Cost = 0.01D^{2.887}$$

3.2.5. Bearings

The bearings in a turbine withstand the varying forces and loads generated by the wind.

$$Cost = 2 \times \left[\left(\frac{8}{600} D - 0.033 \right) \times 0.0092 D^{2.5} \right] \times 17.6$$

3.2.6. Gearbox

The gearbox increases the low rotational speed of the rotor shaft in several stages to the high speed needed to drive the generator.

A three-stage planetary/helical gearbox is selected for this design.

$$Cost = 16.45[MR]^{1.249}$$

3.2.7. Mech brake & HS coupling

Disc brakes bring the turbine to a halt when required.

$$Cost = [1.9894 \times (MR)] - 0.1141$$

3.2.8. Generator

The generator converts mechanical energy into electrical energy and could be either synchronous or asynchronous.

A three-stage drive with high-speed generator is selected for this design.

$$Cost = (MR) \times 65$$

3.2.9. Variable speed electronics

This allows both variable-speed operation as well as “low-voltage ride through” when properly programmed.

$$Cost = (MR) \times 79$$

3.2.10. Yaw drive and bearing

This is the mechanism that rotates the nacelle to face the changing wind direction.

$$Cost = 2 \times 0.0339 D^{2.964}$$

3.2.11. Main frame

This is usually made from steel and must be strong enough to support the entire turbine drive train, but not too heavy.

A three-stage drive with high-speed generator is selected for this design.

$$Cost = 9.489 D^{1.953}$$

3.2.12. Electrical connections

This includes all electrical connections, including switchgear and any tower wiring.

$$Cost = (MR) \times 40$$

3.2.13. Hydraulic system

Includes all hydraulic and cooling system components.

$$Cost = (MR) \times 12$$

3.2.14. Nacelle cover

This is a lightweight glass fibre box that covers the turbine’s drive train.

$$Cost = 11.537(MR) + 3849.7$$

3.2.15. Control safety system

This is used for control, safety, and condition monitoring.

$$Cost = 35{,}000$$

3.2.16. Tower

This is the main structure upon which all other components are erected.

$$Cost = [(0.3973 \times A \times H) - 1414] \times 1.5$$

3.2.17. Foundations

The base on which the tower rests.

$$Cost = 303.24 \times (H \times A)^{0.4037}$$

3.2.18. Transportation

This is the cost of transportation of turbine components from point of manufacture to site.

$$Cost = 1.581 \times 10^{-5}[MR]^2 - 0.0375[MR] + 54.7$$

3.2.19. Roads/civil works

This includes the cost of construction, modification, or rehabilitation of access roads to enable transportation of turbine components to site.

$$Cost = 2.17 \times 10^{-6}[MR]^2 - 0.0145[MR] + 69.54$$

3.2.20. Assembly and installation

This is the cost of equipment assembly and installation on site.

$$Cost = 1.965 \times (H \times D)^{1.1736}$$

3.2.21. Electrical interface/connections

Electrical interface covers the turbine transformer and the individual turbine's share of cables to the substation.

$$Cost = 3.49 \times 10^{-6}[MR]^2 - 0.0221[MR] + 109.7$$

3.2.22. Permits/engineering

Engineering and permits cover the cost of designing and permitting the entire wind facility, allocated on a turbine-by-turbine basis. These costs are highly dependent upon the location, environmental conditions, availability of electrical grid access, and local permitting requirements.

$$Cost = [9.94 \times 10^{-4}(MR) + 20.31] \times (MR)$$

3.2.23. Levelized replacement cost

Levelized replacement cost is a sinking fund factor to cover long-term replacements and overhaul of major turbine components, such as blades, gearboxes, and generators.

$$Cost = (MR) \times 10.7$$

3.2.24. Operations & maintenance cost

O&M costs cover the day-to-day scheduled and unscheduled maintenance and operations cost of running a wind farm.

$$Cost = 0.007 \times AEP$$

3.2.25. Land lease cost

Wind turbines normally pay lease fees for land used for wind farm development. This cost is principally based upon the land used by the turbine.

$$Cost = 0.00108 \times AEP$$

3.2.26. Fixed charge rate

The fixed charge rate (FCR) is the annual amount per dollar of initial capital cost needed to cover the capital cost, a return on debt and equity, and various other fixed charges.

For this model, FCR includes construction financing, financing fees, return on debt and equity, depreciation, income tax, property tax and insurance, and is set to 0.1158 per year.

$$Rate = 11.85\%$$

3.2.27. Project uncertainty

This is caused by unexpected delays - e.g., delays in the supply of materials, shortage of workers, delay in getting licenses etc.

We estimate this amount as a percentage of the turbine capital cost using the sample provided in the NREL report template.

$$Fractional\ Uncertainty = \frac{Project\ Uncertainty}{Turbine\ Capital\ Cost}$$

$$Fractional\ Uncertainty = \frac{162{,}000.00}{1{,}309{,}713.38} = 0.1237$$

3.3. Cost of energy

The Cost of Energy (COE) shall be estimated using standard excel-based template from the Wind Turbine Design Cost and Scaling Model [3] developed at the National Renewable Energy Laboratory (NREL).

The following parameters are specified for the calculations.

- Machine Rating (MR) = 2000 kW
- Rotor Diameter (D) = 44 m
- Rotor Radius (R) = 22 m
- Hub Height (H) = 40 m
- Tower Swept Area (A) = $\pi \times 22^2 \approx 1520\ m^2$

Using the above parameters and the formulas shown in the previous sections, we compute the various elemental CAPEX and OPEX costs. By comparing this cost with the Annual Energy Production, we determine the Cost of Energy (COE).

Cost of Energy (COE) is calculated using the following equation [4]:

$$COE = \frac{FCR \times ICC}{AEP_{net}} + AOE$$

$$AOE = \frac{LLC + O\&M + LRC}{AEP_{net}}$$

Where:

- COE = Levelized Cost of Energy ($/kWh)
- FCR = Fixed Charge Rate ($)
- ICC = Initial Capital Cost ($)

- AEP_{net} = Net Annual Energy Production (kWh/year)
- AOE = Annual Operating Expenses
- LLC = Land Lease Cost
- O&M = Levelized Operating and Maintenance Expenses
- LRC = Levelized Replacement/Overhaul Cost

Considering that the cost model was developed in 2002, and the costs are based on the value of the US Dollars in 2002, adjustment have been made to account for inflation from 2002 to 2021.

In the United States, the Bureau of Labour Statistics publishes the Consumer Price Index (CPI) every month, which can be translated into inflation rate. [5] From this, we obtain that the value of the US Dollar in 2002 is equivalent to $1.46 in 2021.

Using these parameters as input, we obtain the following:

Initial Capital Cost (ICC) = $ 2,034,685.49
Installed Cost per kW = $ 1,017,342.74
Annual Operating Costs = $ 91,622.74
Cost of Energy (COE) = $ 0.06/kWh

4. Cost Analysis

Analysis of the cost metrics for our proposed wind power generation project shall be carried out by first evaluating the distribution of power with wind speed and determining optimal power generation conditions.

4.1. Power curve

The distribution of power with wind speed for our 2 MW wind turbine is shown in the plot below.

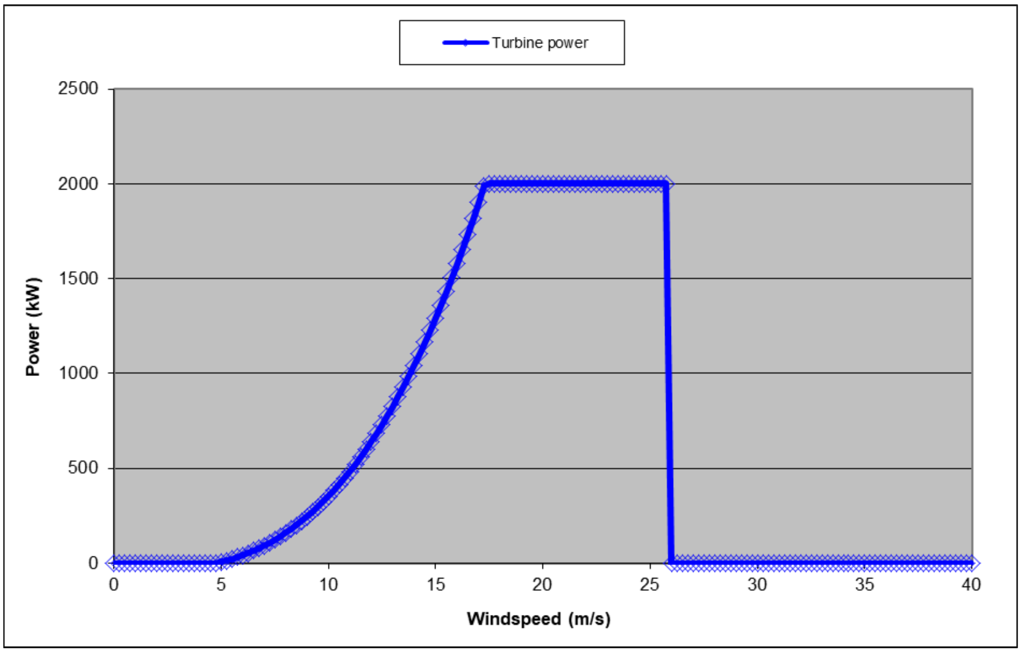

Figure 1 Power curve

The cut-in wind speed is set at 3 m/s and cut-out wind speed at 26 m/s. This ensures that the turbine rotor does not continue to operate at very low speeds where there is little or no power generation. It also helps to ensure that the turbine does not continue to operate at very high wind speeds capable of causing damage and increasing tendency for wear and tear.

We also observe that the wind turbine is able to deliver the rated power of 2 MW at and beyond the rated wind speed. Below the rated wind speed, power generation sharply declines.

The ratio of power generation to the rated power P/P(rated) is an important parameter in wind turbine performance and shall be discussed subsequently.

4.2. Efficiency vs power

From the results of calculation obtained from the Weibull calculation template, a plot of turbine efficiency with power ratio is made.

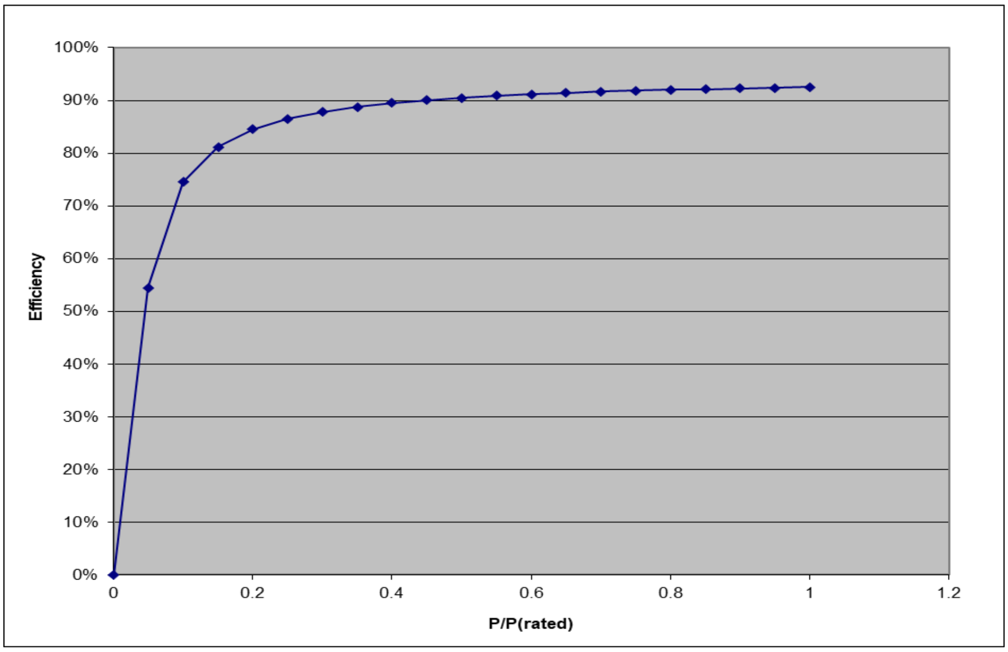

Figure 2 Efficiency to Power ratio Distribution

We observe that the maximum turbine efficiency is 92.5% when the turbine generates power equal to its rated capacity.

Below the rated capacity, the turbine efficiency decreases in a linear manner with a gentle slope till about 40% of rated power generation where the efficiency is about 90%. Between 40% and 15%, the efficiency decline follows a quadratic curve to about 80% efficiency. Below this point, the efficiency declines very sharply to zero.

The 15% power ratio corresponds to power generation of 300 kW and wind speed of circa 9 m/s. This means that the turbine performance decreases sharply at wind speeds below 9 m/s with minimal power generation. The operating costs at this point may then outweigh the benefits in terms of power generation making it uneconomical to run the plant below this point.

4.3. Probability distribution function

From the results of calculation obtained from the Weibull calculation template, a plot of the probability distribution function is made.

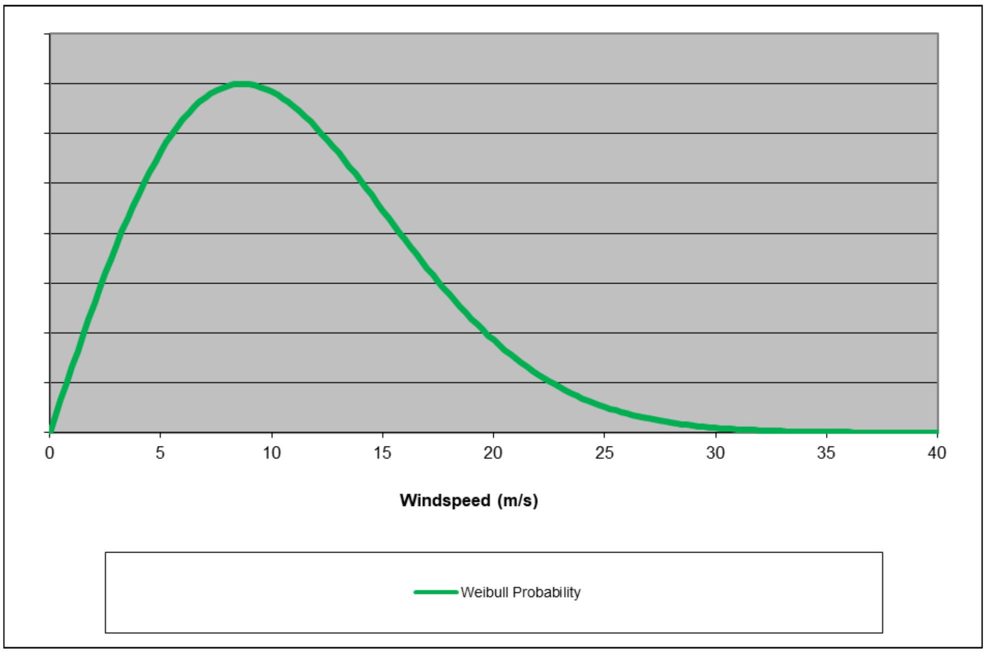

Figure 3 Probability Distribution Function

The formula for the probability density function of the Standard Weibull distribution is:

$$f(v) = kv^{k-1}e^{-(v^k)}\ v \geq 0\,; k > 0$$

The probability distribution depends on a factor, *k,* which is the shape parameter, and the wind speed, *v*, at the hub using the Weibull probability function. This distribution can be used to compute the probability of wind blowing at a particular speed.

Using a k-factor of 2, we observe that the Weibull probability distribution is skewed towards the left, indicating that there is higher probability of having lower windspeeds.

There is a 40% chance of having wind speeds at the rated wind speed and far lower chances of having speeds above it. Chances of having wind speed beyond the cut-off speed of 26 m/s are less than 5%.

We also observe that there is a 90% chance of having wind speeds of about 10 m/s. This indicates power output below the rated capacity for the most part of the turbine operations, resulting in a capacity factor of 29.21%.

4.4. Comparison of energy rates

The closest energy distribution company to Langtang is The Jos Distribution Company. All current grid electricity supply to the region is via this company. Data on the cost of electricity from the company was obtained from the Nigerian Electricity Regulatory Commission (NERC) website and converted to US Dollars using the prevailing exchange rate [1].

Table 2 Electricity Cost in Langtang

Electricity Prices	**Residential**	**Business**
Cost per kWh ($)	0.09	0.14

The Cost of Energy (COE) obtained from our wind power generation project is $ 0.06 per kWh.

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

Considering the presence of a few commercial and industrial outfits within the region, we can assume an average pricing of $ 0.10 per kWh, as this will provide a reasonable estimate on revenues.

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

$$Profit\ per\ kWh = \$\ 0.10 - \$\ 0.06 = \$\ 0.04$$

The total expected annual profit will then be.

$$Annual\ projected\ profit = 0.04 \times 5118.23 \times 10^3 = \$\ 204{,}729.20$$

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

$$Payback\ period = \frac{2{,}034{,}685.49}{204{,}729.20} = 9.9\ years$$

4.5. Future factors

We observe that it will take about 10 years to recoup initial investment made on the proposed wind energy project. However, considering that wind turbines typically last for up to 30 years, the project still appears to be profitable.

Other future factors that are capable of affecting the profitability of the project are briefly discussed below:

4.5.1. Fossil fuels

Apart from the adverse effects of using fossil fuels for power generation (e.g., climate change, greenhouse effects, acid rains etc.), the amount of fossil fuel available worldwide is limited and will continue to decrease with time.

Considering that world population will continue to increase, availability of fossil fuels may become scarce and renewable sources of energy will become more viable.

4.5.2. Incentives

The National Renewable Energy and Energy Efficiency Policy (NREEEP) provides incentives centred around renewable energy, some of which includes Customs duty exemptions on the importation of equipment and materials, tax holidays for local manufacturers, tax holidays on dividend incomes from investments in domestic renewable energy sources, special low-interest loans for renewable energy supply and grants to communities to encourage renewable energy projects.

There are currently no tax credits for renewable energy as the Nigerian market has yet to develop sufficiently to accommodate initiatives of this kind; however, there are plans by the federal government, under the NREEEP, to introduce tax credits for producers of renewable energy appliances and fixtures [1].

This could potentially reduce the initial capital cost of the project and improve profitability.

4.5.3. Renewable energy credits

Nigeria's renewable energy market is still largely new and not sophisticated enough to ascribe special values to electricity from renewable energy in terms of green attributes or renewable energy credits. However, it is important to note that NREEEP proposes a power production tax credit (PPTC) [1].

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

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

5. Results and Discussions

Using available templates, we have estimated the cost of our proposed Wind power generation project. A summary of the energy demands, which ensures there is a constant market for the produced power, as well as analysis of methods used for cost estimation, is presented below.

5.1. Summary of location energy demands

Data on the exact energy consumption of Langtang is not available. However, extrapolation was done based on available national data on per capita electricity consumption. Projection on daily energy demand was also made using extrapolation from available national data as discussed in Assignment 1[1].

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

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

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

Based on a 2016 European Union Energy Initiative report on electricity demand in Nigeria, the grid and off-grid electricity demand for Nigeria was projected at 165 TWh in 2020.

The ratio of the population of Langtang to the entire country based on the 2016 population projection, assuming an even growth rate was obtained as:

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

The electricity demand in Langtang in 2020 is then estimated as:

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

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

The electricity gap in Langtang is thus estimated as:

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

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

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

5.2. Analysis and observations

Using the Department of Energy (DOE)/National Renewable Energy Laboratory (NREL) scaling model, we have computed the Annual Energy Production, Capital and Operating Costs and Cost of Energy (COE). The results are presented in the following tables.

Table 3 Langtang Wind Power Project Turbine Calculations

Langtang wind power project turbine calculations			
100 m windspeed	12.38	m/s	
Weibull K parameter	2.00		
Rated power	2000	kW	

Rotor Dia.	44	meters	
Hub height	40	meters	
Altitude	0	meters	
Air Density	1.225	kg/m3	
Rotor Cp	0.45		
Cut-in windspeed	3	m/s	
Cut-out windspeed	26	m/s	
Power law shear exponent	0.143		
Hub height windspeed	10.86		
Rated windspeed	17.28	m/s	
Conversion Efficiency	0.95		
	0.005		
Soiling Losses	3.5%		
Array Losses	5.0%		
Availability	98.0%		
	Turbine	Weibul Cp	Weibul betz
Energy capture (MWh/year)	5118.23	8524.54	11816.56
Capacity Factor	29.21%		
Energy capture ratio	60.04%		

Table 4 Langtang 20 MW Power Project COE Projection Sheet

LANGTANG 20-MW POWER PROJECT COE PROJECTION SHEET		
Baseline Turbine: 2 MW - 3 Bladed Upwind/Pitch Controlled - 44 Meter Rotor		
Machine Rating, MR (kW)	2000	
Rotor Diameter, D (m)	44	
Rotor Radius, R (m)	22	
Hub Height, H (m)	40	
Tower Swept Area, A (m^2)	1520	
Year	2002	2021
	Component	Component
Component	Costs $1000	Costs $1000
Rotor	80.19	117.08
Blades	40.01	58.42
Hub	28.97	42.30
Pitch mechanism & bearings	11.20	16.36
Drive train, nacelle	733.64	1,071.11
Low speed shaft	0.56	0.81
Bearings	2.30	3.36

Gearbox	218.35	318.79
Mechanical brake, HS coupling etc	3.98	5.81
Generator	130.00	189.80
Variable speed electronics	158.00	230.68
Yaw drive & bearing	5.04	7.36
Main frame	15.38	22.45
Electrical connections	80.00	116.80
Hydraulic system	24.00	35.04
Nacelle cover	26.92	39.31
Control, safety system	35.00	51.10
Tower	34.11	49.80
TURBINE CAPITAL COST (TCC)	813.83	1,188.19
Foundations	25.89	37.79
Transportation	85.88	125.38
Roads, civil works	98.44	143.72
Assembly & installation	12.66	18.48
Electrical interface/connections	158.92	232.02
Permits, Engineering	44.60	65.11
BALANCE OF STATION COST (BOS)	426.38	622.51
Project Uncertainty	153.41	223.98
Initial capital cost (ICC)	1,393.62	2,034.69
Installed Cost per kW for 2 MW turbine (cost in $)	696.81	1,017.34
Turbine Capital per kW sans BOS (cost in $)	457.25	667.59
LEVELIZED REPLACEMENT COSTS (LRC) ($10.7/kW)	21.40	31.24
O&M ($/year/turbine)	35.83	52.31
Land Lease ($/year/turbine)	5.53	8.07
NET ANNUAL ENERGY PRODUCTION MWh (AEP)	5,118.23	5,118.23
Fixed Charge Rate	11.85%	11.85%
COE ($/kWh)	0.0417	0.0609
Note: $1 in 2002 = $1.46 in 2021		

The cost analysis provided above is simplified and excludes the impact of government incentives or subsidies, taxation and system balancing costs associated with variable renewables.

Similarly, the analysis does not consider any penalties on carbon emissions, incentives for renewable energy or the benefits of renewables being insulated from volatile fossil fuel prices.

The Levelized Cost of Energy (LCOE) is calculated using a simplified formula that attempts to limit the impact of financial factors so that the true impact of technical changes can be assessed.

In designing a wind power project, it is critical to evaluate the impact of the design on the system cost and performance. Several elements of the process must be considered: Initial Capital Cost (ICC), Balance of Station (BOS), Operations and Maintenance (O&M), Levelized Replacement Cost (LRC), and Annual Energy Production (AEP).

Towers are an important part of the wind turbine capital cost, with costs being driven by steel prices. However, increased competition and the integration of lightweight materials could result in lower tower costs.

Wind turbine rotor blades are also a key component of turbine capital cost. The key driver behind blade design cost optimization is weight minimisation. Using more carbon fibre in blades, as well as improving the design of blades for aerodynamic efficiency can help reduce weight and costs.

Numerous studies have looked at where cost reductions could be achieved and how large these savings might be. The improved performance of wind turbines and their location in higher average wind speed locations are key factors to reducing the LCOE of wind energy by improving the average capacity factor [6].

the LCOE of wind energy can be reduced significantly by having larger rotors at higher hub heights. This is because, all other factors kept constant, the energy yield of a turbine is roughly proportional to the swept area of the rotors. Also, higher wind resources are available at higher elevations.

By conducting sensitivity on the effect of changes in rotor diameter and tower height on the LCOE of the Langtang wind power project, we obtain the following results.

Table 5 Sensitivity of Rotor Diameter and Tower Height on LCOE

Rotor Diameter (m)	44	56	64	76	90	112
Tower Height (m)	40	50	60	70	80	100
AEP (MWh)	5,118	7,059	8,168	9,400	10,448	11,587
ICC (million $)	2.03	2.25	2.45	2.83	3.40	4.72
LCOE ($/kWh)	0.0609	0.0498	0.0471	0.0467	0.0493	0.0587

A sensitivity plot of the effects of increasing rotor diameter on the LCOE is shown below.

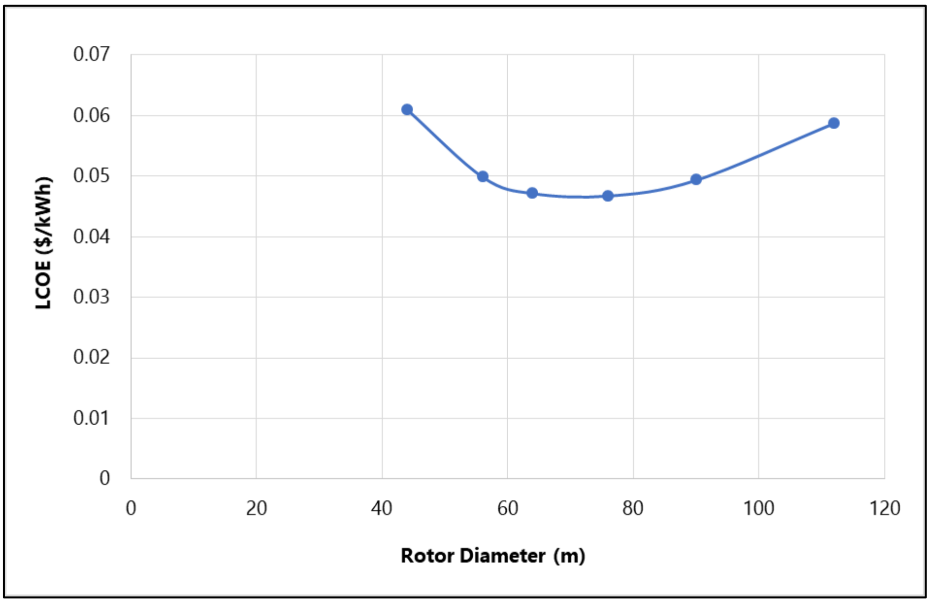

Figure 4 Sensitivity on LCOE with varying rotor diameter

We observe significant improvement in the LCOE with increasing rotor diameter and tower height to an optimum of 76 m and 70 m, respectively. Beyond this point, the effects of increased capital costs outweigh the additional energy produced.

In general, the pathway for LCOE reduction is primarily driven by the increase in AEP through turbine scaling, enhanced control strategies, and reducing wind power plant losses. The secondary driver in decreasing LCOE is through reductions in CAPEX from wind power plant economies of scale, turbine scaling, and efficient manufacturing capabilities. The remaining LCOE reductions are derived from decreasing OPEX through advanced O&M strategies and lowering the cost of capital from increased certainty of future plant performance and reduced risk [7].

6. Conclusion

Detailed cost analysis has been carried out on the 2 MW wind turbine units for the proposed 20-MW Langtang Wind Power Generation project.

The Annual Energy Production (AEP) per turbine unit was computed using the DOE/NREL standardized calculation template. The wind turbine Capital and Operating Costs as well as Levelized Cost of Energy (LCOE) were also estimated using the Wind Turbine Design Cost and Scaling Model templates.

From our analysis, we observe that the turbine performance decreases sharply at wind speeds below 9 m/s with minimal power generation. The operating costs at this point may then outweigh the benefits in terms of power generation making it uneconomical to run the plant below this point.

Also, there is a 40% chance of having wind speeds at the turbine rated wind speed and far lower chances of having speeds above it, with a higher percentage of having wind speeds of about 10 m/s, resulting in power output below the rated capacity for the most part of the turbine operations. This corresponds to a capacity factor of 29.21%.

The Levelized Cost of Energy is driven by the Initial Capital Cost (ICC), Balance of Station (BOS), Operations and Maintenance (O&M), Levelized Replacement Cost (LRC), and Annual Energy Production (AEP), with the capital costs directly related to the rotor diameter and tower height.

By conducting sensitivity on the effect of changes in rotor diameter and tower height on the LCOE, we observe significant improvement in the LCOE with increasing rotor diameter and tower height to an optimum of 76 m and 70 m, respectively. Beyond this point, the effects of increased capital costs outweigh the additional energy produced.

This analysis thus suggests that for optimum design of the 2 MW wind turbine units for the Langtang Wind Power Project, 3-bladed rotors of diameter 76 m and tower height of 70 m could be considered from a levelized cost perspective.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Omenai, S. A. (2024); Feasibility Study for Wind Power Generation in Langtang, Plateau State, Nigeria; Georgia Tech, ME 6701 Project. International Journal of Science and Research Archive. https://doi.org/10.30574/ijsra.2024.13.2.2448

[2] Omenai, S. A. (2024); Design of a 2 MW Wind Turbine for a Proposed Wind Farm Project in Nigeria Using WT-PERF; Georgia Tech, ME 6701 Project. World Journal of Advanced Engineering Technology and Sciences. https://doi.org/10.30574/wjaets.2024.13.2.0644

[3] L. Fingersh, M. Hand, A. Laxson (2006); Wind Turbine Design Cost and Scaling Model; National Renewable Energy Laboratory

[4] Lakshmi N Sankar (2021); Wind Engineering – Cost and Weight Models (Module 6.1); Georgia Tech, ME 6701 lecture Notes

[5] https://www.calculator.net/inflationcalculator.html?cstartingamount1=1&cinyear1=2002&coutyear1=2021&calctype=1&x=66&y=20

[6] International Renewable Energy Agency (2012); Renewable Energy Technologies: Cost Analysis Series; IRENA Working Paper vol. 1 Issue 5/5 (June 2012)

[7] Tyler Stehly, Philipp Beiter, Patrick Duffy (2020); 2019 Cost of Wind Energy Review; National Renewable Energy Laboratory