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Modeling and Assessment of Wind Energy Potential in the Department of Nariño Colombia

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Abstract : This work seeks to evaluate the energy potential of the department of Nariño to different types of wind turbines and this heights; the economic evaluation to establish the viability of renewable energy. The average wind speed was 5.6 m/s with values between 4 and 8.5 m/s, adjusted to the probabilistic Rayleigh model. The results show that the department of Nariño can generate 31,267,194.55 kW/year, depending on the power of the wind turbine (400-3000 kW) and the heights 50, 70 and 90 meters. The economic pre-feasibility indicates that the wind turbine Vestas V80 2000 kW had the lowest generation cost with 0.00414263 USD / kWh, which was considered attractive for the financial indicators of the project.
Keywords : Wind turbine, modeling and simulation, wind potential, alternative energy, Pre-feasibility.

Introduction

Energy demand has increased significantly worldwide with the rapid global economy's development. The need to mitigate this demand has driven the renewable energy generation throughout the world.

Wind energy efficiency is one of the most powerful and profitable ways to meet the demands of sustainable development[1], also it is considered wind energy is an energetic and environmental alternative because it reduces pollution when it satisfies a need.

Some authors affirm that numerous local factors that influence or determine the intensity and periodicity of wind movements must be considered. These factors, difficult to simplify due to their multiplicity, are those that allow to refer to local winds, which are in many places more representative than those of a general character[2].

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In Latin America, research and development programs on renewable energy sources are limited; only in Brazil and Venezuela have been carried out hydroelectric and solar energy projects. The outlook in Colombia is not very good, because the wind and solar energy development is minimal and is represented respectively by the Jepirachi wind farm and small photovoltaic cell systems with a capacity of 2 MW[3].

The main objective of this work is to model and simulate the wind energy potential in the department of Nariño. This mathematical model allows us to analyze the type and height effect of a turbine on the electricity generated by the wind.

Nariño is a Colombia's department with great inequality physiographic level, which makes many regions are not part of the central system or electrical interconnection with marked difficulty in supplying energy service due to difficult geographic access[4].

Experimental

Wind speed data for the department of Nariño, Colombia

The wind speed data for the Nariño's department, were measured using an anemometer. The Institute of Hydrology, Meteorology and Environmental Studies in Colombia (IDEAM) provided the information at 10 m height[5].

Nariño's Department is located in the extreme southwest of the country on the border with the Republic of Ecuador. It has an unequal relief and physiography, three regions are distinguished, zone with mountains, the most predominant is the Cordillera de los Andes that forms the Pastos knot, Pacific Plain is characterized by its vegetation, mangrove zone and humid forest and the Amazon slope formed by the Amazonian piedmont, steep terrain and its covered by humid forests[6].

Methods

Microsoft Excel® was used to obtain Rayleigh distribution Parameters[7], to simulate the electrical energy produced by different wind turbines[8, 9] and economic viability. The turbines used in the simulation have a power of 330 kW, 600 kW, 2000 kW, 3000 KW and 2000 kW.

Correction of Speeds at different heights.

The wind speed data is usually given at a reference height of 10m. For projects which involve kinetic wind are required to correct the height needed, with Equation (1)[10].

$$V = V_{ref} * (Ln\left(Z/_{Z_0}\right)/Ln\left(Z_{ref}/_{Z_0}\right)) \qquad Ec. 1$$

V is the wind speed at a height Z, $\boldsymbol{V_{ref}}$ is the reference speed at a known reference height $\boldsymbol{Z_{ref}}$ and $\boldsymbol{Z_0}$ is the roughness length. This latter being calculated according to study area's physiography, shown in Table 1.

Rayleigh's parameters

The Rayleigh's probability function with its parameter (b) and according to Equation (2), which represents the wind's speed variability in the study area, is used for the modeling of the wind speed profile[7].

$$f(v/b) = \frac{v}{b^2} e^{\left(\frac{-v^2}{2b^2}\right)} \qquad Ec. 2$$

Where V is the average speed, obtained from the wind data provided by the IDEAM, b represents the scale parameter (b> 1), it can be calculated with the Ec.3.[7]

$$b = \sqrt{\frac{1}{2n}\sum_{i=1}^{n} v_i^2} \qquad Ec. 3$$

Table 1. Roughness length according to the type of landscape. Edited from[10].

Roughness length	Landscape type
0,0002	Water surface
0,0024	Completely open ground with a smooth surface, eg, concrete runways at airports, cut grass, etc..
0,03	Open agricultural area without fences or hedges and widely scattered houses. Only softly rounded hills
0,055	Agricultural land with some sheltered houses and hedges of 8 meters high with an approximate distance of 1250 m.
0,1	Agricultural land with some sheltered houses and hedges of 8 meters high with an approximate distance of 500 m.
0,2	Agricultural land with many houses, shrubs and plants, or sheltering hedges 8 meters high with a distance of approximately 250 m.
0,4	Towns, small cities, agricultural land, with many or high protective hedges, forests and uneven and unequal terrain
0,8	Bigger cities with high buildings
1,6	Bigger cities with high buildings and skyscraper

Electrical energy production Simulation (E) using different types of turbines

The power generation was simulated with different power turbines of 330 kW, 600 kW, 2000 kW, 3000 KW and 2000 kW, using Equation (4).

$$E = N_h \int_{vm}^{vM} g(v)F(v)dv \qquad Ec. 4$$

Where v is the annual energy produced (MWh / Year), $g(v)$ is the wind turbine power obtained from the power curve, $F(v)$ the frequency calculated with the chosen distribution model, vM and vm are the values the connection speed and the turbine section (m / s), Nh is the number of hours per year (8760h / year)[8].

Determination of the energy corrected by density.

The annual energy generated by the turbine E, must be corrected by area's density, so the relative humidity of the zone influences the E. First of all, the air density (kg / m3) must be calculated by means of the Ec. 5.

$$\rho = \frac{1}{T}\left[\frac{P}{R_0} - \emptyset P_W\left(\frac{1}{R_0} - \frac{1}{R_W}\right)\right] \qquad Ec. 5$$

Where ρ_0 is the air density 1.225 kg/m^3 (Standard conditions 288.16 K air temperature and pressure 101.325 kPa), P Barometric pressure 101.325 kPa, T zone temperature (K), $\emptyset$ Relative humidity (0-1), R_W Water steam specific constant (461.5 J/kg K), R_0 dry air specific constant (287.85 J/kg K) and P_W Vapor pressure (Pa), calculated from the Antoine equation, Eq. 6.

$$lnP_W = A - \frac{B}{T + C} \qquad Ec. 6$$

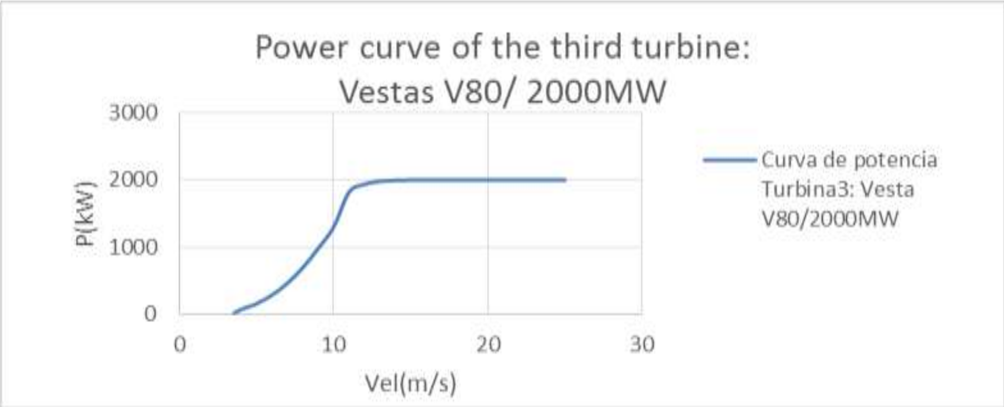
A, B and C are the constants of this equation for water, their values are: 16.2620, 3799.89 and 226.35, respectively[8].

$$E_R = \frac{\rho}{\rho_0} E \qquad Ec.7$$

Wind turbines specifications

Characteristics and costs of each selected wind turbine are shown in Table 2, which was made based on the data of its technical data sheets. As supplementary information should present the power curves of each wind turbine, in Chart 1, the power curve for the Vestas V80 / 2000 Kw turbine is shown.

Chart 1. **Vestas V80 2000 kW turbine power curve**



Economic feasibility Analysis in the wind turbine's implementation in Nariño.

The economic factor is important to determine the viability of the wind turbines implementation.

The cost of electricity in kWh produced for each turbine was calculated from the current value of Present value of costs (VPC) Eq. 8. [10, 11].

$$VPC = I + C_{om}\left[\frac{1+i}{r-1}\right] \times \left[1 - \left(\frac{1+i}{r+1}\right)\right] - S\left[\frac{1+i}{r+1}\right]^t \qquad Ec.8$$

Where, (I) is the initial investment, (C_{om}) operation and maintenance costs, (r) interest rate, (i) inflation rate, (S) salvage value and (t) wind turbine lifetime.

As a determining factor to evaluate the project viability, the net present value (VPN), represented in Equation 9, is calculated. [10, 12].

$$VPN = -I + (P_v E_g - C_{om})\left[\frac{1+i}{r-1}\right] \times \left[1 - \left(\frac{1+i}{r+1}\right)\right]^t - S\left[\frac{1+i}{r+1}\right]^t \quad Ec.9$$

Pv and Eg are sale price and the annual energy generated, respectively.

Another definitive data to review is the investment recovery time (TRI), calculated with equation 10. And it shows us how attractive a project is for an investor. [10, 12]

$$TRI = \frac{log[1 - I \times \left[\frac{r-i}{P_v E_g}\right]\left[\frac{1}{1+i}\right]}{log\left(\frac{1+i}{1+r}\right)} \quad Ec.10$$

Table 2. Wind turbines specifications to be evaluated

Turbine model	ENERCON E33 330 kW	TURBOWINDS T600-48	VESTA V80/ 2000kW	VESTA V90 3kW	ENERCON E82 2000 kW
Nominal power (kW)	330	600	2000	3000	2000
Hub height (m)	44 – 50876	70	80	80	78
Rotor's Diameter (m)	33.4	48	80	90	82
Swept area (m^2)	876	1810	5027	6362	5281
Shovel number	3	3	3	3	3
Connection speed (m/s)	2,5	2,5	3,5	3,5	2
Cutting speed (m/s)	25	25	25	25	25
Price 2017 (USD)	421480,5936	1016198,304	1689926,304	2660632,128	1713636,165

DATA ANALYSIS

Results of wind profile and energy by Rayleigh.

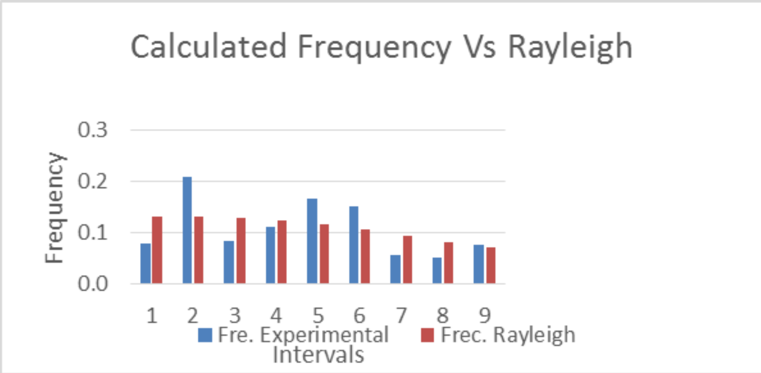
As we first corrected the wind speeds of 10m at the heights of analysis are Z: 50m, Z: 70m and Z: 90m, with a value of roughness length (z0) of 0.4 m use equation (1). At higher altitudes the speed increases, due to the kinetics of the wind. Next, we determine work intervals where we counted the number of times the data is repeated, then we calculate the frequency. With the Rayleigh distribution, the frequency data F (v) was determined and it was found that it is adjusted exactly to the wind speed, compared with the Weibull distribution for some parameters (k = 4 and c = 6). To check if the model is adequate, it was evaluated by the Chi square and RMSE (Root Mean Square Error) criteria, with equations 11 and 12, respectively. In chart 2, you can see the data distribution and verify that the Raileigh function is suitable for modeling the frequency.

$$X^2 = \frac{\sum_{i=1}^{N}(y_i - x_i)^2}{N - n} \qquad Ec. 11$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2\right]^{1/2} \qquad Ec. 12$$

$\boldsymbol{y_i}$ is the i-nth probability value of the experimental data, $\boldsymbol{x_i}$ is the i-nth value of the estimated data with the Rayleigh distribution, N is the number of observations and n is the number of constants of the model. When applying the criteria, values close to zero are obtained, indicating a good data fit, $X^2 = 0{,}0022572290$ and RSME = 0.044793139.

Chart 2. Experimental frequency and frequency calculated by the Rayleigh distribution, compared to the selected speed intervals



Annual energy produced by a wind turbine.

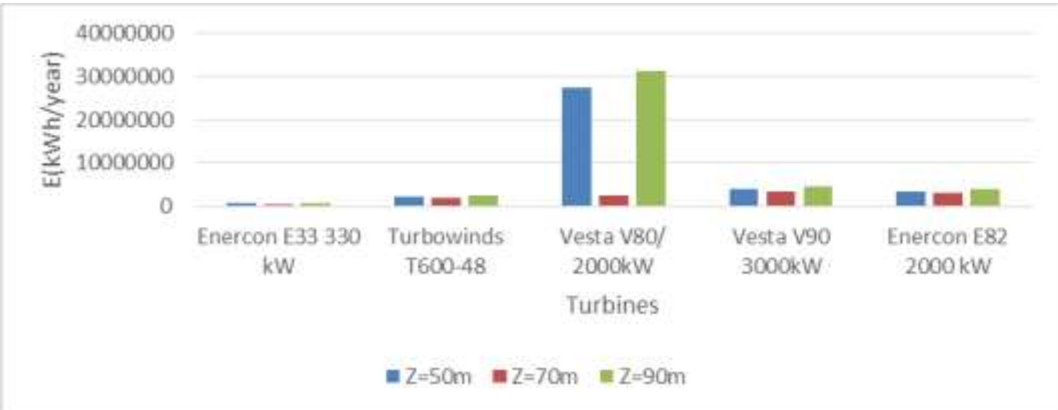
The annual energy production is estimated using equation 4 and then corrected with equation 7, for the turbines and heights selected in the Nariño department. Results are shown in graph 3. The annual energy increases with the increase in the height and turbine's capacity. The annual energy production for a small turbine (600 kWh) is low because it is between 480 and 642806 kWh / year, while the biggest turbines (2000 and 3000 kWh) produce 2660632 kWh / year, approximately 6 times more.

Analysis of cost power ratio produced.

The economic factor is important to determine wind power project viability. The electricity cost in kWh produced for each turbine at different heights is shown in Figure 3, and was calculated from the current value of costs (PVC). The initial investment (I), the maintenance costs and repair of the operation (Com) were considered 25% of the turbine annual cost (price /useful life). The interest rate (r) and the inflation rate (i) were 18% and 5.6%[13], respectively. It was considered that the salvage (S) is 10% of the turbine's price and its useful life (t) is 20 years. PVC is calculated using equation 8 and the energy cost per kWh is obtained by dividing the PVC by the total kWh produced for each wind turbine during its useful life[3, 9, 11].

Chart 3 is shown the specific USD / kWh price of five wind turbines at three different heights, it is observed that for the VESTAS V-80 2000 Kw turbine, the cost of the kWh is lower at a height of 70 and 90 m, with values of 0.047 USD / kWh and 0.00414 USD / kWh, respectively, and compared with the others it has a better USD / kWh ratio, therefore for the economic pre-feasibility analysis in the Nariño, Colombia this turbine was selected.

Chart 3. Annual energy produced from five wind turbines for three different heights.



Economic parameters analysis

Chart 4 show the VPN values calculated from equation 9. From the figure it is concluded that the VPN always decreases when increasing the interest rate, regardless of the energy produced selling cost by the wind turbine.

The project would be attractive at any price and to lower interest rates to 40% due the PVN maintains a trend of acceptability greater than zero, making the project profitable.

Chart 4. Variation of the VPN respect to the interest rate at different sale prices of energy at a height of 90m

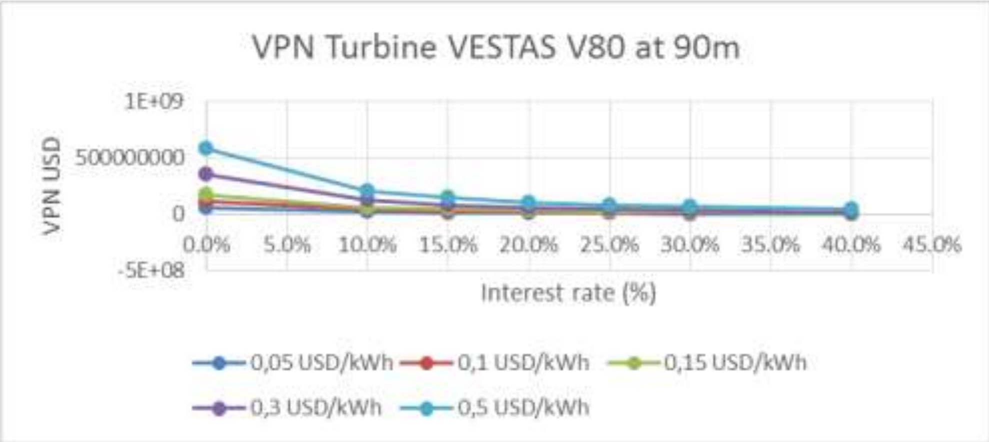
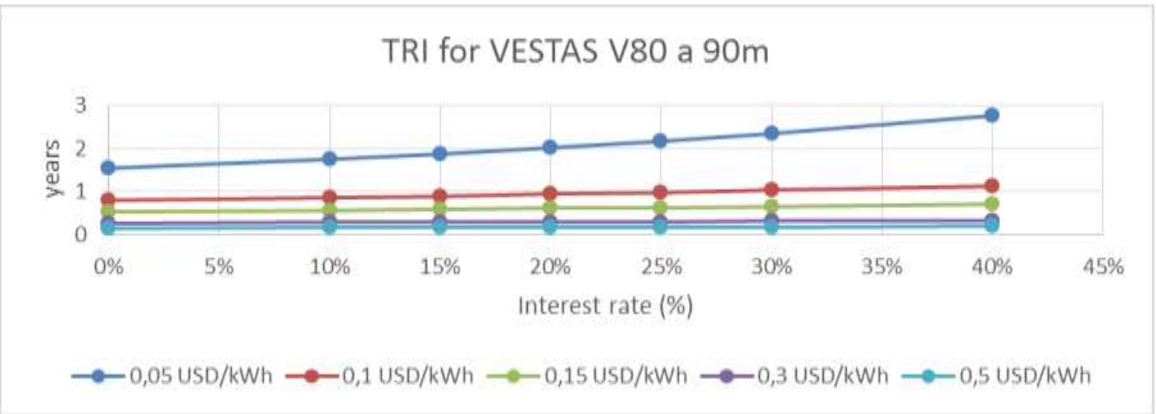


Chart 5. Specific price of five different wind turbines for three different heights in Nariño.

Chart 5 shows the variation of the return on investment time (TRI) respect to the interest rate at different energy sale prices. It is analyzed that regardless of the energy price as the interest rate increases, the time of recovery of the investment increases. It is possible to recover the investment made in less than 3 years for the Vestas V80 turbine 2000 kW, for investors at any price the attractive interest rates range between 7-20%.

Chart 6. TRI variation with respect to the interest rate at different energy sale prices at a height of 90m



The internal return rate indicates the value of the interest rate for which the VPN is equal to zero[9]. Table 4 shows that the project is interesting for any sale price, given that the TIR is higher than the Attractive Minimum Rate of Return (TMAR)[9,11].

Table 4. TIR according to the sale price analyzed

PRICE (USD/ kWh)	TIR %
0,05	68,236113
0,1	131,17404
0,15	195,246472
0,3	385,737323
0,5	639,734226

900	43.07

Conclusions

The highest wind average speed (7.6 m/s). The Rayleigh function models the profile of wind speed data in Nariño. This work is an analysis of the energy produced by the wind in Nariño, Colombia, with the purpose of discovering its potential, at different heights.

After analyzing the power generated by a turbine, the ratio USD / kWh and economic parameters was synthesized in the turbine with lower power generation cost and profitability of the project is the Vestas V-80 (2000kW).

It is recommended for better precision and statistical distribution, that data be constant, every hour, so a distribution function that fits to the safety effects could be used, which is that the calculated frequency is lower than the real one.

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