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A Life Cycle Cost Analysis in Wind Energy Projects in Colombia

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Abstract. The demand for energy has been increasing and with this the need to find new sources of electricity generation for the system. In Colombia, different investigations have been developed in which different sources of generation are considered. In this article, we will be based on the study done in de Atlas of the wind of Colombia considering wind power as a source of generation. This article presents a case study in the LCOE analysis in generation projects of renewable energy through wind technology. Crystal Ball is used for this analysis as a simulation tool for different scenarios in order to determine the cost kilowatt hour in a wind farm in Colombia. In addition, in this article evaluates the financial feasibility of installing a wind farm in Colombia by comparing the cost kilowatt hour of energy generated in different regions of the country with the energy costs presented in the last year in Colombia and contemplating the energy policies of Colombia that generate economic benefits in the installation of renewable energy generation sources.

Keywords: LCOE analysis, renewable energy, wind energy.

1 Introduction

As energy demand grows worldwide, it is growing the need to look for new generation sources such as solar, wind, biomass, among others. Over time its use has become one of the solutions more effective and efficient for sustainable development according to a study by [5].

If generalized measures are not implemented and effective to meet the demand for energy such as efficient production, technological developments and environmental awareness, according to studies registered in [9] the demand for primary energy is likely to expand 2 to 2.5 times by 2050; And 3.5 to 4.5 times for the year 2100.

Renewable energies generate different benefits, as mentioned by the authors [12] where they state that demand growth and decline in prices they can be better than those predicted by conventional energy sources.

This paper studies the possibility of installing a wind farm in Colombia, this study is made due to the volatility in energy prices and the decrease in emissions of CO_2 generated by wind energy and a financial analysis has been taken into account. For this, the document Atlas of Colombia made is taken as a reference by [16], which shows a collection of maps where with the distribution surface wind space shows the country's wind potential.

The financial analysis is based on an LCOE model given by the ratio between the annual cost of energy produced in a year for a certain place and the density of energy generated in said place. The LCOE methodology (Levelized Cost Of Electricity) is used to compare costs kilowatt hour between different renewable energy production projects and determine the minimum value at which the energy produced can be sold. The LCOE metric is calculated with the cost ratio and energy density as shown in equation (1) that generates the cost per kilowatt hour $(\$/KWh)$:

$$LCOE = \frac{CAE_t}{P_n}, \tag{1}$$

where CAE_t is the equivalent annual cost that includes: maintenance cost, cost of operation and initial cost; t is the period in years that for this work are considered 20, and P_n is the density of energy generated during a year.

2 Methodology

For this study, the work done by presented on [16] the map is taken into account of Colombia a monthly average wind and this is carried out the methodological steps. For this study, we consider:

- Places: 16 places are located in different departments of Colombia that they are classified by [16] as the places with the best wind potential in the country.
- Average speed: Places that have an average wind speed are taken greater than or equal to 3m/s for being places where a wind farm could be installed. This information is obtained in [16].
- Data: in the cost analysis life cycle was considered the cost of a wind turbine, variations that are modeled with different distributions such as the average

wind speed, wind energy density, cost per square meter of the land where it would take the installation of the wind farm and maintenance costs thereof.

2.1 Formulation

The amount of energy transmitted to the rotor is expressed as density of power, which is directly related to air density. Power density o wind energy density (*P/A*) is given by equation (2) that depends on the density of air (ρ) and wind speed (*v*), these are measured in kilograms per cubic meter and meters per second, respectively.

$$\frac{P}{A} = \frac{1}{2}\rho v^3 . \tag{2}$$

The density of the air is given by:

$$\rho = \frac{P}{TR^*}, \tag{3}$$

with:

$$R^* = R\left(1 + \frac{e}{P}\right), \qquad e = \exp\left(\frac{-6763{,}6}{T}\right) - 4{,}9283\, lnT + 54{,}23,$$

the universal constant of ideal gases is *R* with a value of *286; 8Jkg/K*, *P* is the pressure atmospheric expressed in Newton per square meter and *T* is the air temperature expressed in degrees Kelvin.

The table 1 shows the data obtained from equation (3) and the energy density obtains by the equation (2) for the different places.

To carry out the modeling based on the LCOE methodology, an analysis is carried out in the which are considered the following places: Camilo Daza airport, Galerazamba, El Embrujo airport, Sesquicentenario airport, and Gachaneca. These places were determined as those with a lower coefficient of variation in wind energy density. Subsequently, they are collected data to calculate the LCOE in each of these places, a characteristic that they share these places is the wind turbine that would be installed, so a quote is made for a wind turbine through the Aelos wind turbine company.

The cost per square meter varies by location, so a price per meter is made square as close as possible to the possible location of the wind farm, due to the variety that presents the cost per square meter within the same place, in each case models a triangular distribution where the minimum, maximum and maximum prices are considered most likely as found in different sources of real estate sales.

According to different wind power generation projects, maintenance costs vary as the project progresses, starting with 2% on the cost of the investment and ending at the end of the useful life of a wind power generation project that considered twenty years in with 3% on the same cost. At the moment it is not known exactly in some reference the moment in which this change can be determined, by this reason the triangular distribution is used to model this variable, considering as value minimum 2%, the most likely 2.5% and the maximum as 3% of the initial investment.

Table 1. Matrix of data used for analysis.

Place	Average wind speed (m/s)	Average air density (kg/m^3)	Average wind energy density (W/m^3)
Galerazamba	5,9	1,15	119,19
Gachaneca	5,5	0,89	74,14
Sesquicentenario airport	5,1	1,15	76,35
La Legiosa	4,1	0,96	33,16
El embrujo airport	4,0	1,12	35,98
Almirante Padilla airport.	4,0	1,14	36,67
Obonuco	3,5	0,86	18,53
Camilo Daza airport	3,3	0,89	16,07
Urrao	3,0	0,96	17,72

Table 2. LCOE values without tax benefits.

Place	Minimum	Maximum	Most probable
Galerazamba	641,81	685,41	662,72
Sesquicentenario airport	961,34	1047,46	1004,51
Gachaneca	1011,89	1078,33	1045,78
El embrujo airport	2135,99	2250,45	2190,58
Camilo Daza airport	4517,48	4867,67	4682,36

Table 3. Correlation between the LCOE without tax benefits and parameters.

Place	Land purchase	Maintenance cost	Wind energy density	Average speed of energy
Galerazamba	-0,4983	-0,805	-0,2666	0,0029
Sesquicentenario airport	-0,7148	-0,6281	-0,2091	0,0045
Gachaneca	-0,4833	-0,8271	-0,2351	-0,0133
El embrujo airport	-0,3088	-0,9156	-0,2343	-0,0099
Camilo Daza airport	-0,6757	-0,6829	-0,2215	-0,0149

On the other hand, the average wind speed is taken as a variable for the LCOE because to the variation that it presents month by month for the same place. This is modeled with a distribution Weibull with scale and shape parameters that differ for each month, the parameters of this distribution are taken from the work done by the [16].

Because the density of the energy given by equation (2) varies are the wind speed, energy density is a variable that changes for each month, which is why taking account that its minimum, maximum and most probable value is known, and that the amount of sample data is limited, this variable is modeled with a triangular distribution taking as parameters the minimum and maximum value of the energy density for the year, and as more value probable energy density for each month.

Taking into account the variations and distributions mentioned above, it is done the financial analysis calculating an LCOE for each month in each place. For these calculations you use the Crystal Ball application and make a simulation with 5000 iterations taking as parameters land cost per square meter, maintenance cost, speed average wind and energy density. The LCOE is defined as a dependent variable.

3 Results

The results of the simulations performed with the application Crystal Ball for the calculation of the LCOE in each place. Simulations include two cases: without tax benefits and with tax benefits. These benefits include a deduction special income tax and accelerated depreciation that are granted by law 1715 of the year 2014 in Colombia. This section first presents the descriptive analysis of the sample and the latent variables. Then, we discuss results from the model evaluation, including its effects.

3.1 Without Tax Benefits

Table 2 shows the results of the minimum, maximum and most probable value of the LCOE value for each of the places. These are ordered ascending according to the LCOE obtained. In this you can see that the place with the lowest cost of sale is Galerazamba and the highest cost is from Camilo Daza airport, meaning the LCOE of Galerazamba about 14% of the most likely value of the LCOE in the Camilo Daza airport.

Table 3 shows the correlation values between the parameters taken for the simulation and the LCOE of each place.

This shows that the highest correlation in the most places are presented in the cost of maintenance and are negative, which means that for each place the parameter that most negatively affects the LCOE is the cost of maintenance, that is, the higher the maintenance cost, the higher the LCOE. On the other hand, at the Sesquicentenario and Camilo Daza airports the correlation is high with respect to the purchase of the land, this is caused by the high costs per square meter of the land with regarding the other places.

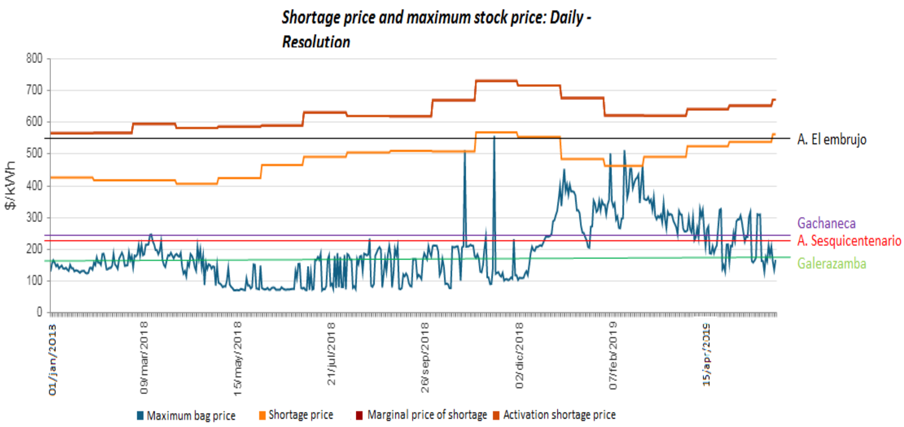

Fig. 1. Stock price compared to calculated LCOE values.

Table 4. LCOE values with tax benefits.

Place	Minimum	Maximum	Most probable
Galerazamba	148,37	189,33	168,69
Sesquicentenario airport	195,99	276,33	237,65
Gachaneca	226,77	289,15	258,72
El embrujo airport	497,12	615,89	554,97
Camilo Daza airport	874,90	1242,57	1056,14

Table 5. Correlation between the LCOE with tax benefits and parameters.

Place	Land purchase	Maintenance cost	Wind energy density	Average speed of energy
Galerazamba	-0,3766	-0,9031	-0,0655	0,0008
Sesquicentenario airport	-0,4351	-0,8888	-0,0774	0,0029
Gachaneca	-0,3658	-0,9167	-0,0562	-0,0188
El embrujo airport	-0,2121	-0,9716	-0,0564	-0,0152
Camilo Daza airport	-0,5482	-0,8149	-0,0377	-0,0083

3.2 With Tax Benefits

As of 2014, tax benefits are generated according to Law 1715 "Por medio de la cual se regula la integración de las energías renovables no convencionales al Sistema

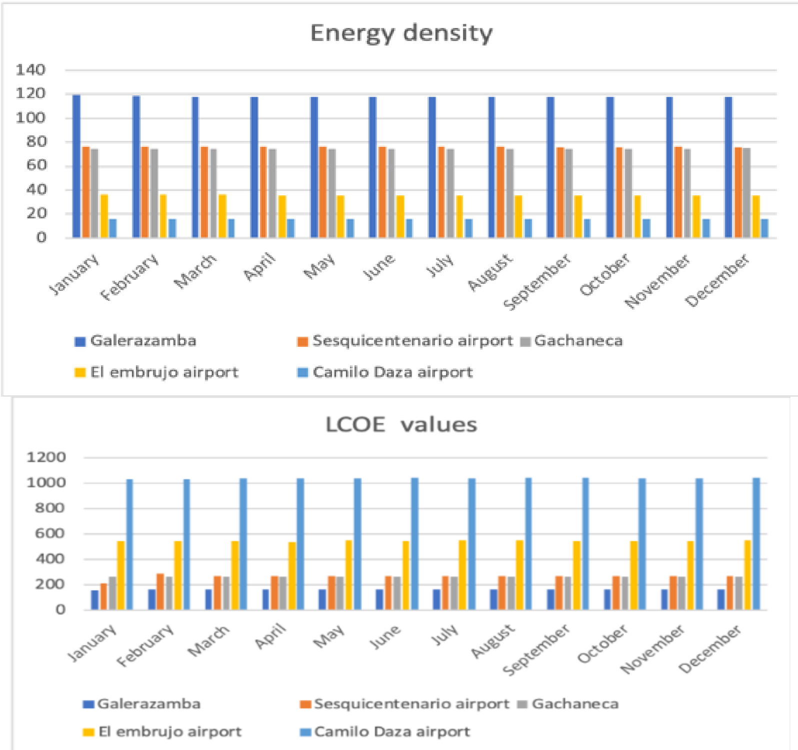

Fig. 2. Graph of LCOE relationship and energy density.

Energético Nacional". Given this law, for this project is considered the special deduction of income tax that consists of deducting for each taxable year a value not exceeding 50% of the taxpayer's liquid income, before to subtract the deduction; and accelerated depreciation where the global annual depreciation rate. It cannot exceed 20%. This generates changes in the LCOE for each place, which is why run the simulations for each zone again.

Table 4 shows the results of the LCOE analysis with tax benefits for Each of the places. These are sorted in ascending order according to the LCOE obtained. It can be seen that the place with the lowest cost of sale is Galerazamba and the one with the highest cost is Camilo Daza airport, the LCOE of Galerazamba being around 16% of the value plus LCOE likely at Camilo Daza airport.

Table 5 shows the correlation values between the parameters taken for the simulation and the LCOE with tax benefits of each place. This shows that the higher correlation is presented with the cost of maintenance and is also negative, which means that for each place the parameter that most negatively affects the LCOE is the cost of maintenance. That is, regardless of where the wind farm is installed, a decrease in the cost of maintenance would generate a decrease in the LCOE. Sales costs calculated in the analysis take into account the benefits tax and are similar to the costs obtained in the financial analysis made by the authors in [14].

This analysis is done with seven different power turbines between 6,000 kW and 2,750 kW in regions of Colombia that are not connected to the national electrical system and have an annual average speed greater than 4m/s. This shows that variations in the financial analysis of these types of projects. It does not affect the cost of sale kilowatt hour. Therefore, there are different variables that are they can take into account for the execution of a wind power generation project, giving relevance to social, environmental and economic aspects.

Image 1 shows the stock and shortage prices given by XM (www.xm.com.co) on a daily basis from January 1, 2018 to June 4, 2019, in addition, LCOE average values were added considering the tax benefits granted in law 1715 that were applied to each of the five places studied in this document, these values behave similarly in each month as observed in the different overlay graphics shown in this section.

The Energy Density chart consolidates the energy densities for the five places with lower coefficient of variation and on the LCOE chart considering benefits tax values are consolidated in the base case of the statistics for each place.

When comparing these two graphs, it can be seen that the higher the density value of wind energy for each place in a general way, the lower the LCOE corresponding to the same place. Preserving this correspondence for each place, which could be assumed that one of the main factors that influence the LCOE corresponding to each place is the density of energy present in said place. This observation is valid taking into account the denominator of the formula equation 1.

4 Conclusions

The key factors for the installation of a wind farm are the average speed of the wind and wind energy density, these are used for the life cycle cost analysis. From the average speed 16 places are selected with wind potential in Colombia and with the density of wind energy the production of wind energy in different places.

The generation capacities of the wind farms for the five locations in order to coefficient of variation of wind energy, and determined, from the LCOE analysis, that Galerazamba and Gachaceca are the best places for the installation of a wind farm in Colombia.

The maintenance cost is a determining factor to calculate the LCOE in each place and the tax benefits of Law 1715 of 2014 are a great incentive for the execution of a wind farm in Colombia, reducing the LCOE between 74% and 77% in each place.

The variation that occurs in wind energy density per month and the variation in Weibull distribution parameters that vary in average speed for each month, are parameters that modify the output variable, the smoothed cost of LCOE energy per month in each of the places.

When considering the tax benefits granted in law 1715 of the year 2014 in this class of technology makes it competitive against the market prices observed in the market wholesaler for Galerazamba, A. Sesquicentenario, Gacaneca and A. El embrujo.

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