International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.9, No.05 pp 614-623, 2016

Modeling and Assessment of Wind Energy Potential in the Cartagena City

Álvaro Realpe*, Brenda Chamorro, Gezira De Avila

Department of Chemical Engineering, Research Group of Modeling of Particles and Processes, Engineering Faculty, Universidad de Cartagena, Colombia

Abstract : Through the years, new sources of renewable energy are investigated to replace the energy obtained from fossil fuels; it is important to analyze the wind profile to develop alternative energy projects. Colombia is part of the countries implementing such practices; in particular the city of Cartagena by its geographical location, to determine the wind potential to generate electricity.Modeling and simulation ofproductionof electrical energy generatedfrom windwas carried out, as well as its economic assessmentto establishviability inthe implementationof windas a renewableenergy source.Data of speed and direction of wind, andtemperature and humidity of the air were collected daily during 8 months using a weather station (PCE-FWS 20) located in the tower of the University of Cartagena. The average wind speed was of 4.00 m/s with values between 2.38 and 6.14 m/s, which were adjusted to the probabilistic model of Weibull.The results show that in the city of Cartagena can be generated from 180.28 to 838.23 MWh / year, depending on the power of the wind turbine (500-3000 kW) at a height of 40 meters. The economic analysis indicates that the wind turbine Vestas 3000 KW had the lowest cost of generation with $ 385.97 / KWh, which was considered attractive for the financial indicators of the project.

Keywords: Wind energy, modeling and simulation, wind turbines, alternative energy.

1. Introduction

Excessive useof fossil fuels hascontributedto the climatechangethat threatenshuman security.Today,the energy crisis andenvironmental pollutionforces thehuman beingto seek alternative energy [1-10].Wind energystands out asa generatingsource ofenergy, cleanand sustainable, replacing graduallythe traditionalenergy model.According tothe report of theGlobalWind Energy Council(GWEC), in 2013a globalinstalled capacity of318,137MWwas reported,an increase of almost200,000MWin the last fiveyears.However, the annual marketwas reduced from 10GWto35 467MW, which is attributed to theprecipitous drop inUSwind farms.The prospects for 2014 and beyond seem to be encouraging [11].The use of wind as an energy source is performed through wind turbines, in which the wind moves the blades and transforms the rotational mechanical energy into electrical energy, which can be used in diverse applications [12-15].These turbines are continuously optimized, increasing its economic viability and allowing to be installed in many countries of the world, with very favorable results [16].

Colombia has strong air currents due to its location; investigations made by the Ministry of Mines and Energy highlighted various regions of the country with wind potential outstanding as is the case of Guajira department with the wind park of Jepírachi, that implements wind turbines to produce energy with an annual capacity of 92.872 MW [17]. However, in the rest of the country had not yet been implemented this technology, which makes necessary to perform studies on modeling and simulation of the wind potential available, energy annual productionand of environmental impact, in order to estimate areas conducive to the installation, and its economic assessment.

Currentlythehigh demand ofenergy of theBolivar capital on thenational electricsystem causesrationingaffectingresidential areasin the region.In this project was studiedthe tourist area ofCartagenathat hasstrongwinds coming from theCaribbean Sea, where the wind directionis not obstructedby mountains(Cerro de la Popa),and determined the economic and technical feasibility of the implementation of Wind Energy.

2. Materials and Methods

The wind speed was measured daily in the period September 2013 to January 2014 using the weather station PCE-FWS 20 manufactured by PCE instruments (Iberica). Microsoft Excel® was used to obtain the parameters of Weibull distribution [18], simulate the electrical energy produced by different wind turbines [19, 20] and economic viability. Turbines used in simulation have potency of 500 kW, 1000 kW, 2000 kW, 3000 kW, 4000 kW and 5000 kW

2.1. Information and analysis of wind aata

The tourism sector of Cartagena is an area with a high demand for energy and with intermediate wind speed [7]. Initially, it was determined the air density using the equation (1).

$$\rho = \frac{1}{T} * \left[\frac{P}{R_0} - \phi P_W \left(\frac{1}{R_0} - \frac{1}{R_W}\right)\right] \qquad (1)$$

where "P" is thebarometric pressure (101,325 Pa);"Φ" is the relative humidity(range0-1); "T" is the temperature (K); "R_0" is the specificconstantof dry air(287.85 J/KgK), "R_W" is thespecific constantof water vapor(461.5 J/kgK) and"P_W"isthe vapor pressure(Pa) that isdetermined by theAntoine equation(2).

$$LnP_W = A - \frac{B}{T + C} \qquad (2)$$

where A=16.2620, B=3799.89 and$C$=226.35.

2.2. Weibull parameters

The modeling of the wind speed profile was obtained by the Weibull probability function with their corresponding parameters (α andβ) according to the equation (3), which represents the variability of wind in the study area.

$$F(v) = \frac{\alpha}{\beta}\left(\frac{v}{\beta}\right)^{\alpha-1} \cdot e^{-\left(\frac{v}{\beta}\right)^{\alpha}} \qquad (3)$$

where $F(v)$ represents the statistical probability of the occurrence of a certain wind speed; β is the scale parameter (m/s) whose value is close to the average speed; and α is the dimensionless parameter of the form. Parameters (α and β) were determined by fitting wind speed data using equation (4), where $W(v)$ is the accumulation distribution of Weibull function.

$$w(v) = 1 - \cdot e^{-\left(\frac{v}{\beta}\right)^{\alpha}} \qquad (4)$$

The density of wind energy ($\overline{P}$) was determined using the equation (5) considering the statistical probability distribution F(v), and where ρ represents the density of air.

$$\overline{P} = \frac{1}{2}\rho\int_0^{\infty} v^3 \cdot \frac{\alpha}{\beta}\left(\frac{v}{\beta}\right)^{\alpha-1} \cdot e^{-\left(\frac{v}{\beta}\right)^{\alpha}} \cdot dv \qquad (5)$$

2.3. Simulation of the production of electrical energy (*E*) using different types of turbines

power generation was simulated with different wind turbines of power ratings of 500 kW, 1000 kW, 2000 kW, 3000 kW, 4000 kW to 5000 kW [20], using equation (6):

$$E = N_h \int_{v_m}^{v_M} g(v) \cdot F(v) dv \qquad (6)$$

where "*E*" is the annual energy produced (MWh/year), *g(v)*is the power curve of the wind turbine, v_M and v_m are the values of the connection speed and cutting of the turbine (m/s), N_h is the number of hours per year (8760 h/year).

2.4. Analysis ofeconomic viabilityin the implementationof wind turbines inCartagena

The economic factor is important for determining the viability of the implementationof wind turbines. The cost of electricity by kWh produced for each turbine in Cartagena was calculated from the present value of costs (PVC). The assumptions for calculating the PVC of electricity are similar to those used by Alnaser [21], Habali et al. [22], and Ahmed and Hanitsch [23-25].

3. Results and Discussion

3.1. Meteorological conditions in Cartagena: Temperature, relative humidity, air density and wind speed

Figure 1 indicates the daily behavior of the temperature in Cartagena during the months of study. It can be seen that the maximum value recorded in the period of study was 36.1 °C and the minimum value of 27.2°C; meanwhile, the Table 1 shows the monthly averages of temperature in the city of Cartagena ranging between 28°C and 29°C. Figure 2 shows the relative humidity with average value of 78% ranging between 44% and 84%.

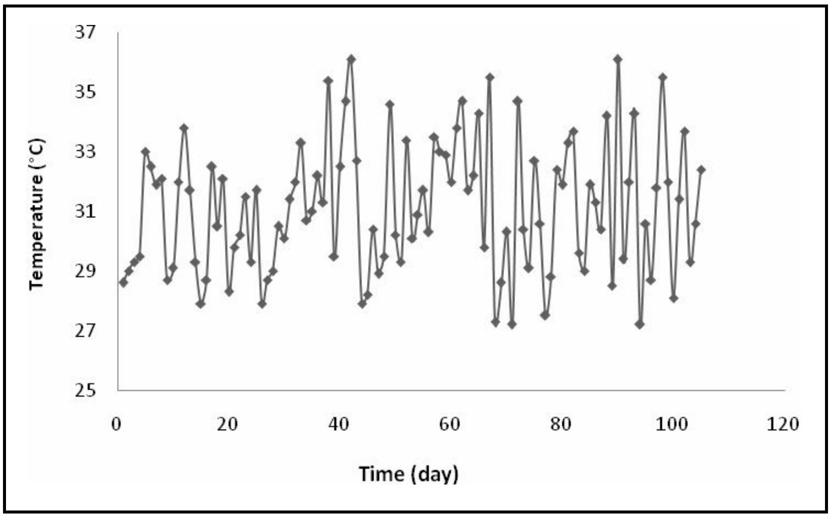

Figure 1. Daily measurement of temperature in Cartagena

Table 1. Monthly average temperature in Cartagena

Month	Temperature (°C)
May	28.6
June	29.0
July	28.7
August	28.9
September	28.7
October	29.0
November	28.7
December	28.8

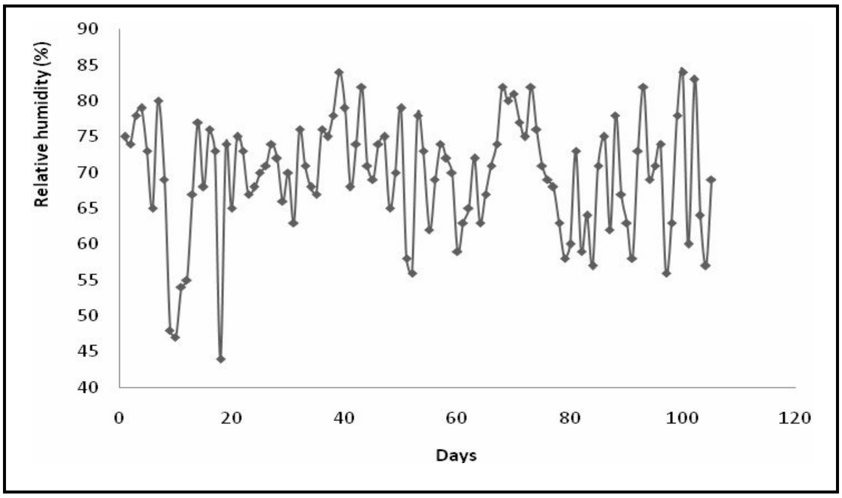

Figure 2. Relative humidity in Cartagena

Air density(kg/m^3)was calculatedtaking into accountthe relative humidity, temperature and pressure withequation (1). Table3 shows themonthly averageof air density, which is close to 1.13 Kg/m^3.

Table 3. Monthly average air density in Cartagena.

Month	Air density (Kg/m^3)
May	1.137
June	1.116
July	1.132
August	1.121
September	1.132
October	1.116
November	1.132
December	1.127

Figure 3 presents the variation of the wind speed during the months of May to December 2013 at a height of 40 m.The maximum value ofthe wind speedwas 9.2m/sandthe minimum value of2.4m/s. Table4 showstheaveragewind speed ofeach month, whichrange from2.2m/sand 3.6m/s. These values ofwind speedare similar tothose ofother coastal areas, for example,the East Coast ofIndiareportingspeeds from1.3m/sto2.7m/s[26].

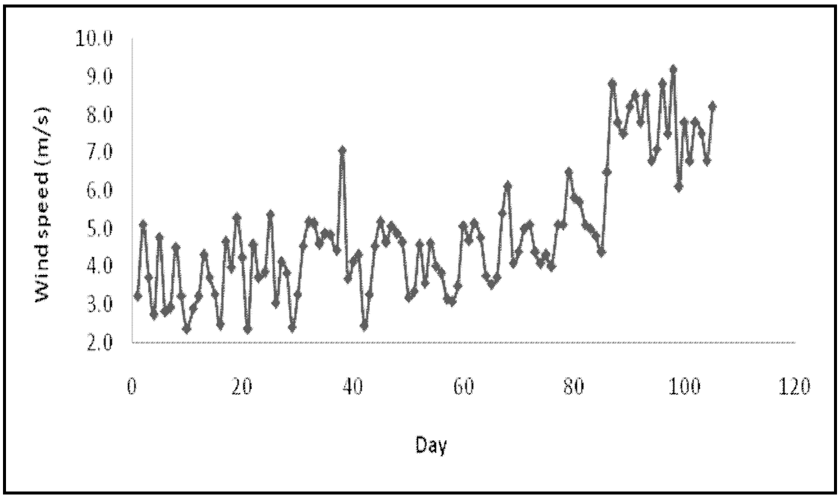

Figure 3. Wind speed in Cartagena

Table 4. Average wind speed of each month in Cartagena

Month	Wind speed (m/s)
May	2.6
June	2.2
July	2.8
August	3.5
September	3.3
October	3.6
November	2.5
December	3.7

3.2. Modeling the wind potential for energy production

Weibullparametersare determined bylinear fit ofequation (4), which are necessaryfordetermining thewind energydensity usingequation (5).Figure 4 showshigh correlation with aR^2 nearto1. The parametersfound representsthe frequency distributiongiven inFigures5.

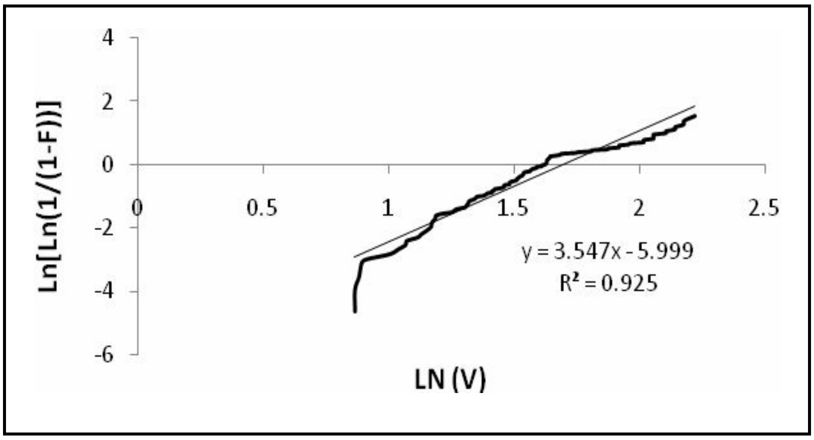

Figure 4. Linear fit of equation (4) forcalculatingthe Weibull parameters

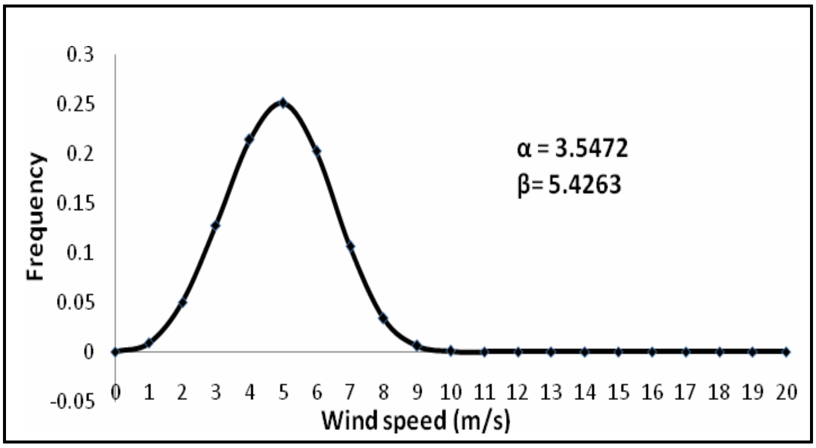

Figure 5. Frequency distribution of Weibull for wind speed data of Cartagena city

Figure 5 showspeaks ofhigh frequency ofwind speedsbetween 4 and 6m/s. The oddsare low forwind speeds lessthan 1m/sor greater than9 m/sat a height of40.

Energy Density

The Weibull parameterswere replaced in the equation (5), andwind power densityof75.48W/m^{2}was determined, this being relatively lowcompared withvaluesfrom other sectorsof the Caribbean regionasPuertoBolivar, Las FlórezandGalerazambawith219.5W/m^2,194.4W/m^{2}and132.6W/m^{2}at10meters of height, respectively[27].

Simulation of electricity Production Using Different Types of Turbines

Manufactures of wind turbines used in the simulation were Bonus (Denmark), Vestas (Denmark), XEMC DARWIND (Holland), Turbowinds (Belgium). Figure 6 represents the curves of powers of each wind turbine and Table 5 shows different specifications for each turbine.

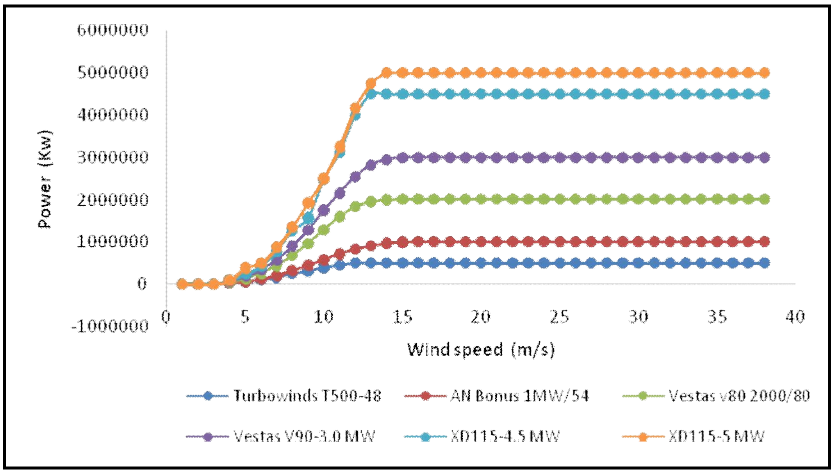

Figure 6. Power curves of the wind turbines

Table 5.Specifications for each wind turbines

TURBINE MODEL		**TURBOWIN DS T500-48**	**AN BONUS 1 MW/54**	**VESTAS V80 2000/80**	**VESTAS V90-3.0 MW**	**XEMC DARWIND XD115-4.5MW**	**XEMC DARWIND XD115-5MW**
Rated power (Pr) (kW)		500	1000	2000	3000	4000	5000
Hub height (m)		70	50	80	80	80	90
Rotar diameter (m)		48	54.2	80	90	115	115
Swept area (m^2)		1810	2300	5027	6362	10207	10387
Number of blades		3	3	3	3	3	3
Cut in wind speed (m/s)		3	3	4	4	4	4
Nominal wind speed (m/s)		14	15	15	15	13	14
Cut off wind speed (m/s)		25	25	25	25	25	25
Price/ (US $)		962309	1050202	1600309	2519538	3137048	4020781

Table 6 shows relation between factor [g(v) ·F(v)] of equation 6 and the Weibull distribution (F(v)) at different wind speed and considering the turbine potency.

Table 6. Factor [g(v) ·F(v)] of equation 6 and the Weibull distribution (F(v)) for turbine Vestas V90-3.0 MW

Wind speed	Turbine potency g(v)		Weibull distribution F(v)		Energy [g(v)*F(v)]
0	0		0		0
1	0		0.008777404		0
2	0		0.049961387		0
3	0		0.12785159		0
4	85000		0.214186278		18205.83363
5	200000		0.251175249		50235.04979
6	350000		0.202419302		70846.75585
7	590000		0.106016083		62549.48885
8	900000		0.033402362		30062.12536
9	1283000		0.005774592		7408.801463
10	1750000		0.000494001		864.5026028
11	2160000		1.86817E-05		40.35241308
12	2550000		2.76698E-07		0.705580558
13	2820000		1.41147E-09		0.003980345
14	2950000		2.1656E-12		6.38851E-06
15	3000000		8.67107E-16		2.60132E-09
16	3000000		7.81326E-20		2.34398E-13
17	3000000		1.35825E-24		4.07476E-18
18	3000000		3.8832E-30		1.16496E-23
19	3000000		1.54797E-36		4.64392E-30
20	3000000		7.25635E-44		2.17691E-37
21	3000000		3.35617E-52		1.00685E-45
22	3000000		1.27869E-61		3.83606E-55
23	3000000		3.33421E-72		1.00026E-65

Figure 7 shows the curve between wind speed and factor *[g(v)·F(v)]* for calculating the area under curve using Simpson 3/8 method, which is the produced energy.

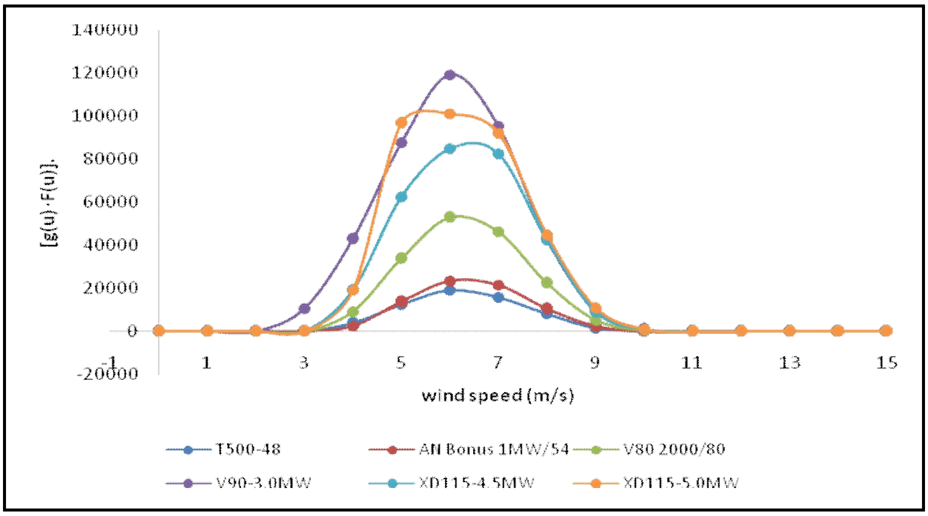

Figure 7. Energy generated at different wind speeds

Figure 7indicates thathighest energy(kWh 70846.12) was obtainedwitha speed of 6m/s, which is the wind speedwith a second frequency of0.202. Meanwhile,withthe wind speed(5 m/s) with higher frequency0.251generated alow energy of 50235kWh.Similar behaviorwas reported in[28]. Moreover, Figure 8 showsthe annualenergy produced byeach generator, which is equivalentto the area underthe curve shown in Figure7.The highest valueof energy producedwas obtained forthewind turbine Vestas V90-3.0 MW.

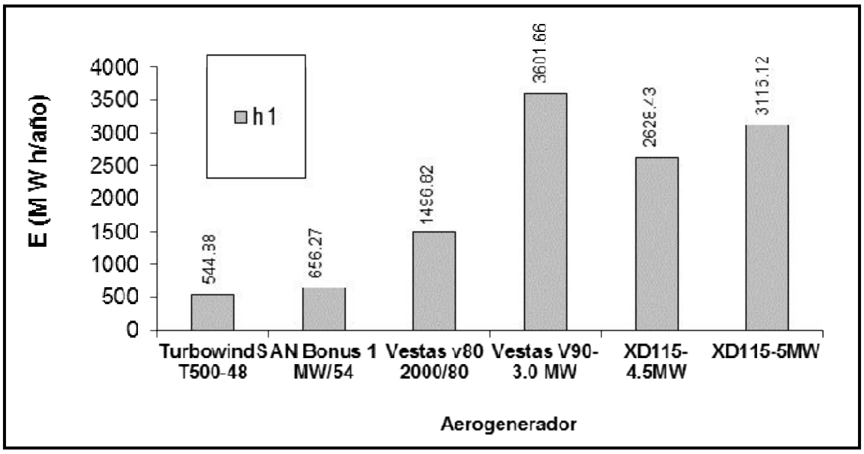

Figura 8. Energía anual generada por cada aerogenerador

3.3. Analysis ofthe economic feasibilityfor the implementationof wind turbines inCartagena

The economic feasibility study considers some parameters commonly used in the implementation of wind farms, as the interest rate of 18%; inflation of 7%; useful life of 20 years; operation and maintenance costs of 25% of the annual cost of the turbine and the scrap value of 10% of the plant cost. Table 7 details the steps to estimate the cost of producing a kWh for the wind turbine T500-48 MW.

Table 7. Cost of energy produced with wind turbine T500-48

Energy generated KWh/year “5”	544876
Useful life (years) “6”	20
Price of wind turbine (US$) “1”	962309
Economic parameters	
Cost of installation (Price of turbine * 20%) “2”	192461
Total investment (US$) “3=1+2”	1154771
Annual cost of wind turbine “4”	48115
Energy generated during 20 years “8=5*6”	10897525
Operation and maintenance cost “9= 1.5%*2”	12028
Interest rate	0.12
Inflation rate	0.07
Scrap value	115477
Present value of cost	954294
Price of 1 kwh (US$)	0.0876

Figure 9 indicates that the cost of each kWh decreases with increasing the power of the wind turbine; obtaining the best results with the turbine Vestas V90-3.0 MW.

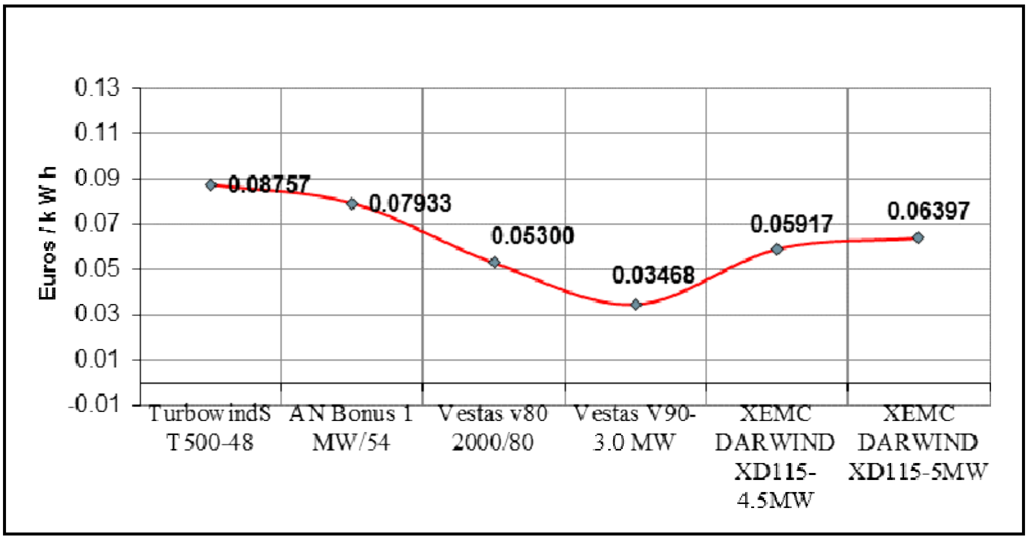

Figure 9. Cost of energy produced for each type of wind turbine

4. Conclusions

The wind power density was determined; However, calculated value is lower than reported in other regions of country such as PuertoBolivar, Las FlórezandGalerazamba, due to low wind speed in Cartagena city.The average wind speed highest (3.7 m/s) was in December. The Weibull function models the profile of wind speed data of Cartagena city, and according with the Weibull functionthere are low probability of repetition of wind speeds lower than 1 m/s and higher than 9 m/s.The economic analysis determined that lowest cost of electricity generation was obtained with wind turbine Vestas V90-3.0 MW

Acknowledgements

Authors are grateful to the Administrative Department of Science, Technology and Innovation of Colombia (Colciencias) and to the University of Cartagena by the funding of this research project under the Young Researchers and Innovators program from 2012 to 2013.

References

1. Beydaghi, H., Synthesis and characterization of new proton conducting hybrid membranes for PEM fuel cells based on poly(vinyl alcohol) and nanoporous silica containing phenyl sulfonic acid, International journal of hydrogen energy: 36(20), 13310-13316 (2011).
2. Realpe A, Mendez N, and Acevedo M, 2014, Proton Exchange Membrane from the Blend of Copolymers of Vinyl Acetate-Acrylic Ester and Styrene-Acrylic Ester for Power Generation Using Fuel Cell, International Journal of Engineering and Technology, 6(5), pp. 2435-2440.
3. Abdulkareem, A. S., C. A. Idibie, H. C. Piennar, L.D Van Dyk, L.D. y S.E Iyuke, Synthesis and characterization of proton exchange membrane using polystyrene-butadiene rubber, Energy Sources, Part A: 32(7), 591–606 (2010).
   Bai, Z. W., M. F. Durstock, y T.D. Dang, Proton conductivity and properties of sulfonated polyarylenethioether sulfones as proton exchange membranes in fuel cells, Journal of Membrane Science: 281(1-2),508-516 (2006).
4. Realpe A., Méndez N., Toscano E. and Acevedo M., Síntesis y Caracterización Fisicoquímica de una Membrana Cargada con TiO2 Preparada a Partir de un Copolímero de Éster Acrílico y Estireno, Información Tecnológica, 26(5) 2015, 97-104.
5. Realpe A., Romero K, and Acevedo M, "Síntesis de Membranas de Intercambio Protónico a Partir de Mezcla de Poliéster Insaturado y Látex Natural, para su uso en Celdas de Combustible", Información Tecnológica, 26(1), pp. 55-62, 2015

6. Realpe, A., M. Acevedo and G. De Avila, "Effect of Vulcanization Process on the Polymeric Membranes Prepared Using Rubber for Application in a Fuel Cell", International Journal of Applied Engineering Research, 10(8) pp. 20239-20247, 2015.
7. Realpe, A., Y. Pino, and M. Acevedo, "Synthesis of A Proton Exchange Membrane Obtained From SEBS Copolymer for Application ina Fuel Cell", International Journal of Applied Engineering Research, 10(6) pp. 15905-15913, 2015.
8. Realpe A, Pino Y., Acevedo M., Effect of Sulfonation of SEBS Copolymer on the physicochemical properties of Proton Exchange Membrane, International Journal of Engineering and Technology, Vol 7 No 4 Aug-Sep, 1438-1442, 2015.
9. Realpe, A., Barrios K, and M. Acevedo,Proton Exchange Membranes With Titanium Dioxide Prepared By Sulfonation Of Rubber, International Journal of Applied Engineering Research, Volume 10, Number 2 (2015) pp. 5023-5030.
10. Carbajales-Dale, M., Barnhart, C., y Benson, S. (2013). ¿La industria eólica, incluso con costes de almacenamiento de energía, es sostenible? http://dailyfusion.net/2014/03/wind-industry-energetically-sustainable-27447/
11. Realpe, J. Diazgranados, M. Acevedo, Electricity generation and wind potential assessment in regions of Colombia, DYNA, Vol. 79, núm. 171, 2012.
12. Realpe A., A. Salamanca-Echeverri, Effect of spacing between electrodes on the hydrogen generation, International Journal of Applied Engineering Research, Volume 10, Number 14 (2015) pp 34262-34264.
13. Realpe., A., J. Orozco, and M. Acevedo, 2015, "Wind Power For Hydrogen Production Using A Spiral Electrolyzer", International Journal of Applied Engineering Research, 10(4) pp. 9175-9183.
14. Realpe A., Salamanca A., and Acevedo M., "Effect Of Electrolyte Type On The Hydrogen Production Using A Plate Electrolyzer", International Journal of Applied Engineering Research, 10(9) pp. 23871-23880, 2015.
15. Portal de Energías Renovables. (2008). Energía eólica. http://www.energiasrenovables.ciemat.es /suplementos/sit_actual_renovables/eolica.htm.
16. Empresas públicas de Medellín (EPM). (2004). “Parque eólico Jepírachi: planeamiento y construcción del proyecto, I parte”.
17. Vogiatzis, Kotti, Spanomitsios, & Stoukides. (2004). Analysis of wind potential and characteristics in NorthAegean, Greece. Renewable Energy, 1193–1208.
18. Zhou, Yang, & Fang. (2006). Wind power potential and characteristic analysis of the Pearl River Delta region, China. Renewable Energy, 739–753.
19. Ettoumi, Hamid, Lassaad, & Nabila. (2008). Comparative simulation of wind park design and siting in Algeria. Renewable Energy, 2333–2338.
20. Alnaser W., Assessment of the possibility of using three types of wind turbine in Bahrain. Renewable Energy. 3 (2–3), pp. 179–84, 1993.
21. Habali S, Hamdan MAS, Jubran BA, Zaid AIO. Wind speed and wind energy potential of Jordan. Solar Energy. 38 (1), pp. 59–70, 1987.
22. Ahmed, A., Shata, R. Hanitsch., Evaluation of wind energy potential and electricity generation on the coast of Mediterranean Sea in Egypt. Renewable Energy. 31, pp. 1183–1202, 2006.
23. Ahmed A., Shata, R. Hanitsch., The potential of electricity generation on the east coast of Red Sea in Egypt. Renewable Energy. 31, pp. 11597–1615, 2006.
24. Ahmed A., Shata, R. Hanitsch., Electricity generation and wind potential assessment at Hurghada, Egypt. Renewable Energy. 33, pp. 141–148, 2008.
25. Sultan AL-Yahyai, Yassine Charabi & otros. (2010). “Assessment of wind energy potential locations in Oman using data from existing weather stations”. Renewable Energy, Volume 14, Pages 1428–1436.
26. Ricardo L., andVenecia Y.,(2011). “Estudio y evaluación del recurso eólico en Colombia para su aprovechamiento como fuente de energía eléctrica”. Grade Project, Universidad de Cartagena.
27. Tafur A., and Pizza A., (2013). “Modelación y evaluación del potencial eólico como una fuente de generación de energía eléctrica en la zona costera de Cartagena”.Grade Project, Universidad de Cartagena.

*****