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Study of Wind Persistence and Density of Wind Power in La Guajira-Colombia

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Abstract

This paper presents the results of the analysis of persistence of wind speed from a statistical point of view applying the concepts of the autocorrelation function, conditional probability and wind duration curves for two weather stations. The name of the stations are Puerto Bolívar and Riohacha in the Department of La Guajira, Colombia. Initial data for the analysis is from historical hourly data provided by the IDEAM during the period 2006 - 2012. Additionally, monthly averages wind power density was calculated to estimate the power generated by future wind farms that could be installed in the Department of La Guajira. The obtained results for the three evaluated concepts indicate that the Puerto Bolívar, located on the northern coast of La Guajira is the most suitable place to generate energy with the wind. Even when the autocorrelation function, conditional probability and wind duration have same result under high wind potential at the location studied, a noticeable difference is observed between them, because of the correlation function and the wind duration curve are based on meteorological conditions, and the conditional probability depends on the truncated speed established in order to determinate the “high wind” and “calm wind” two stages.

Keywords: Wind speed, wind power, autocorrelation function, conditional probability, useful persistence series

1 Introduction

Increased dependency on oil and other fossil fuels pushed the environmental deterioration of the planet, leading to a significant climate change. A more rational use of the resources is need in order to improve the actual conditions. The global energy matrix shows that only 2 % of all produced energy corresponds to renewable sources. In Colombia, only 0.4 % of the produced energy is generated by smaller hydroelectric plants and wind farms. Although by 2028 according to the UPME it is expected that 6 % of all energy produced in Colombia would be environmentally friendly [1].

A brief evaluation of South American countries energy production shows a wide spectrum that varies from Brazil that has more than 190 wind farms with an average capacity of 32 MW, to Paraguay that does not have any wind farms, although wind resource evaluation projects have being developed [2]. Brazil, Chile and Uruguay produce more than 93 % of all wind energy in South America [3]. Projects have been proposed for the creation of wind farms in the Colombian Caribbean, as shown by documents published by the Ministry of Mines and Energy of Colombia [4]. Just as it was the Jepírachi wind farm in the department of La Guajira with capacity for 19.5 MW in 2002, it is currently the only electric power generation plant based on wind potential [5]. More recently, statistical studies carried out in the Colombian Caribbean coast focused on the analysis of the potential of their natural resources to be used as renewable energy have been listed [6]–[9]. Information gathered during mentioned projects has been published in wind and solar atlases of Colombian territory [10], [11]. Koçak in 2002 [12] studied the persistence of wind in northeastern Turkey, from speed duration curves. To complement the wind analysis, in 2008 Koçak [13] proposed the inclusion the methods autocorrelation function and conditional probability but it was concluded that the method of speed duration curves is the best method for studies of persistence because it marks the contrast between the different stations under study. In 2009, Koçak [14] posed an alternative to the models of persistence previously studied by him and arises the analysis of fluctuations without trend. In 2010, Yoreley-Cancino [15] studied the persistence of winds for the state of Veracruz, Mexico, using the function methods of autocorrelation, conditional probability and speed duration curves; concluding that the coast stations have greater persistence due to their geographical characteristics. In other studies, Cancino-Yoreley [16] conducted a study of the electrical demand capacity of the Mexican electricity sector, comparing the effect of different energy generation methods, implementing wind analysis and data collection for five meteorological stations and two anemometric stations in the state of Veracruz – Mexico. In 2011, Masserana [17] calculated the persistence of winds in the Malaysian peninsula, by applying unit root tests and equality of variances, concluding that this study did not provide the information necessary to identify areas with high wind resource and proposes to continue investigating.

In 2013, Agüera-Pérez [18] presented a special and easy-to-implement model for wind prediction based on persistence models. In 2014, Ahmed Mohandes [19] proposed to make short-term estimates of the wind energy potential based on persistence concept.

In Colombia, the use of wind energy as an alternative source of energy is not widely spread; therefore, studies should be conducted to investigate their potential. Initially it is necessary to evaluate the persistence of wind and wind power density. In this article results of the evaluation the persistence of the wind using the function methods of autocorrelation, conditional probability and speed duration curves is reported and discussed. Finally, to measure the capacity of future wind farms, the available wind power density was estimated.

2 Materials and methods

2.1 Site location and data collection

The Department of La Guajira, located in the northernmost part of Colombia and in turn of the entire South American continent, presents great marine and coastal influence in its landscape, mainly arid and semi-arid lands [20].

The sea breeze and the trade winds of the Northeast, during most of the year, influence the climate regime in this zone of the country. The trade winds also transport the clouds to the north-east side of the Sierra Nevada de Santa Marta, which is why this region, which corresponds to Baja Guajira, becomes the one with the greatest precipitation in the department. In contrast, the remaining territory, corresponding to the Middle and Upper Guajira, has scarce rains with values that do not exceed 500 mm/year [21].

The analysis of the winds in the Department has been carried out from the historical meteorological series of speed and direction registered every hour at a height of 10 m during a period of 6 years, from January 1st, 2006 until December 31th, 2012, supplied by *Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia* (IDEAM). These values were recorded in the meteorological stations Almirante Padilla Airport (ATP), and Puerto Bolívar (PTB), which coordinates are reported in Table 1.

Table 1. Location of the meteorological stations Almirante Padilla and Puerto Bolívar

	Station	Department	City/Town	Latitude	Longitude	m.s.n.m.
1	Almirante Padilla Airport	Guajira	Riohacha	11°32´N	72°56´W	5
2	Puerto Bolívar	Guajira	Uribía	12°11´N	71°55´W	0

2.2 Statistical analysys

Statistical analysis of wind persistence is one of the most successful methods in the world to locate possible areas for wind farms. This parameter can be explained as a measure of the average duration of the wind speed within a given range of values for a particular region [15]. In this study the properties of persistence are evaluated from the methods of conditional probability, autocorrelation function, and speed duration curves, which are used satisfactorily by other authors in different regions of the world [13]. The wind power density available in the wind is a design parameter to quantify the energy per unit area that can be taken advantage of the study area [22-23]. In studies of wind, it is essential to know the persistence of the speed, to evaluate the viability to implement future wind farm.

2.2.1 Auto-Correlation Function

One way to characterize persistence is through the autocorrelation function, which is very useful for finding repetitive patterns within a time series. This statistical method determinates a value to compare series, beginning from the most important values of their respective correlograms, where the values are the autocorrelation coefficient of order 1 (r_1) and the lag (k_0) when the function passes through zero, the lag (k_m) for which the function reaches its first minimum [15].

$$r_k = \frac{\sum_{i=1}^{n-k}(v_i-\bar{v})(v_{i+k}-\bar{v})}{\sum_{i=1}^{n}(v_i-\bar{v})^2} \quad (1)$$

To obtain a measure of persistence more reliable it is convenient to combine the information of r_1 and k_0 as

$$P_{ACF} = \frac{1}{2} r_1 (k_0 - 1) \quad (2)$$

therefore, high values of P_{ACF} will have high persistence indexes. In case the autocorrelation coefficient is not canceled, the delay value k_m, is used, for which the autocorrelation function reaches its first minimum. In this way, the calculation of persistence is done by the expression:

$$P_{ACF} = \frac{1}{2} r_1 (k_m - 1) \quad (3)$$

2.2.2 Conditional Probability

The conditional probability is defined as the probability that an event A occurs, knowing that another B event also occurs. For the application in the analysis of the persistence of the wind, it is necessary to establish a minimum speed that it is necessary to overcome, sometimes called truncation speed. In case of wind assessment this speed corresponds to the starting speed of wind turbines and commercially is 3.5 m/s at a height of 50 m.

The conditional probability can be considered as a measure of persistence, estimated for at least two consecutive hours, which means the information supplied by this value is little because there is not enough evidence of how long this persistence parameter is valid. To correct this, the probability condition includes q reference points in order to consider the past information as follow

$$\hat{P}\left(v_t = {}^{w}/_{v_{t-1}} = w, v_{t-2} = w, \dots, v_{t-q} = w\right) \quad (4)$$

achieving the conditioning of the probability of occurring a speed superior to the truncation velocity corresponding to previous hour, or two, three, four, etc.; So that q is directly related to persistence. If the value of q for which this probability is canceled is taken, then it will represent the maximum length of the series of persistence of the wind

$$\hat{P}\left(v_t = {}^{w}/_{v_{t-1}} = w, v_{t-2} = w, \dots, v_{t-q} = w\right) = 0 \quad (5)$$

High persistence will correspond a high value of q.

2.2.3 Speed Duration Curves

The speed duration curves (CDV) show the cumulative distribution of the wind speed over a certain period of time. They are graphs in which the wind speed is shown on the ordinate axis and the percentage of time for which the wind speed is equal to or greater than a particular speed value in the abscissa P_{v_i}. In the speed duration curve, the value $P(v_o)$ for the truncation rate v_0, is used as an indicator of persistence and is denoted by P_{CDV}.

$$P_{CDV} = P(v_0) = P(V \geq v_0) \quad (6)$$

2.2.4 Wind Power Density (WPD)

The wind power density can be calculated as follow

$$WPD = \frac{1}{2n}\sum_{i=1}^{n} \rho v_i^3 \quad (7)$$

The above equation should only be used for individual measurement records (per hour, every 10 minutes, etc.) and not for long-term average records. The available power density is directly proportional to the area swept by the blades of the wind turbine but it depends mainly on the speed hub, which means that if a increment of 10 % in speed is achieved, the available power density increases by 33 % [24].

3 Results and discussion

3.1 Autocorrelation Function Persistence (PAC)

Figure 1 shows that the ATP graph crosses zero, so the value is k_0 corresponding to said delay. In the PTB station the delay value to evaluate the persistence is that where the autocorrelation function registers its first minimum k_m.

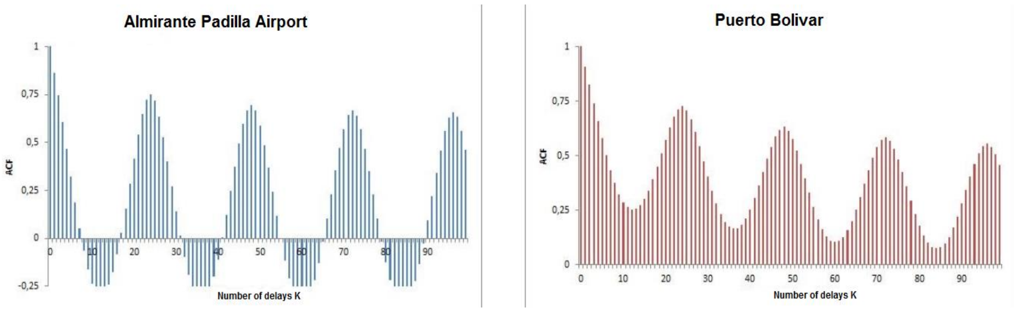

Figure 1. Autocorrelations of the series of data analyzed.

The value of r_1 for PTB is higher than 0.90 whereas that of ATP approaches 0.90, which demonstrates the existence of a strong correlation. Persistence was calculated by means of recovered data and the results are presented in Table 2. Showing that although the two stations under study are located in the same region, to the north, where the PTB station is located, there is a greater Persistence (P_{ACF}).

The best value of persistence obtained with the three methods, as evidenced in Table 2 is Puerto Bolívar, a coastal zone surrounded by the desert, which determines that they have the best characteristics of persistence and wind speeds, on the contrary Of Almirante Padilla, located in the interior of the city of Riohacha, which finds in the roughness of the city the reason for its low average speed and low levels of persistence.

Table 2. Summary of the data obtained with Persistence Analysis methods.

STATION	**ATP**	**PTB**
Persistence by Autocorrelation Function (P_{ACF})	3	5
Persistence by Conditional Probability (P_{PC} (h))	137	3573
Persistence by Speed duration curves (P_{CDV}(%))	73	91

The persistence values obtained with the Autocorrelation function are very different from those that result from the Conditional Probability method and from the Speed Duration Curves. In the first case very similar values are obtained for all the stations whereas in the second and third case, PTB is by far superior to ATP. These results indicate that the methods of conditional probability and speed duration curves offer valid results because they clearly reflect the differences in the persistence of the wind speed between the stations.

3.2 Wind Power Density

Considering a monthly average from the individual data, in September, October and November in Puerto Bolívar the wind power density present the lower values, around 100 W/m^2, with the highest peak in the month of March with a wind power density higher than 280 W/m^2 (Figure 2).

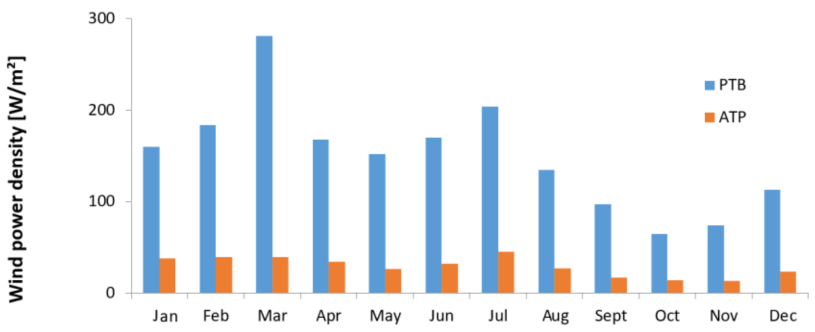

Figure 2. Power density per W/m^2 average.

In the rest of the months it was found values in the range between 113 W/m^2 and 204 W/m^2, while the wind power density in Almirante Padilla was around 50 W/m^2 as shown in Figure 2 for data recovered at a height of 10 meters. In order to determinate the energy production of a wind turbine is necessary to calculate the wind power density profile according to the surface roughness.

4 Conclusion

The most important factor in choosing an area where wind farm is intended to be installed is wind speed. To carry out a complete analysis of this speed it is essential to know the properties of persistence in order to guarantee the most suitable for the electricity generated by the wind. The stadistical methods has been applied to hourly data of wind speed corresponding to two weather stations located in the Caribbean region of Colombia during the years 2003-2013. The results obtained in this study indicate that the northern coast of La Guajira is the most suitable place to generate energy from the wind. This result was foreseeable, since the strongest winds of the Guajira peninsula take place at the north of that location. Puerto Bolívar, located on the north coast has the best characteristics of persistence and wind speed finding in the trade winds, the main engine to start a large-scale wind project. With the calculated power density, it is possible to measure the theoretical capacity that could be generated by a wind turbine and therefore a wind farm. In this study it was shown that Puerto Bolívar has the best characteristics of power density. According to the results obtained, the north region of the Departments of La Guajira presents a huge potential for the implementation of wind farms as sources of clean energy conversion.

References

[1] Plan energético nacional. Colombia: ideario energético 2050, Bogotá, Colombia, 2015.

[2] E. Garcia, Ministerio De Obras Publicas Y Comunicación De Paraguay, 2014. [Online]. Available: http://www.ssme.gov.py/vmme/index.php?option=com_content&view=article&id=1643:paraguay-incluira-energia-eolica-y-solar-en-su-matriz-energetica&catid=96:sample-news&Itemid=552. [Accessed: 21-Mar-2015].

[3] The wind power. Wind energy market inteligence, 2014. [Online]. Available: http://www.thewindpower.net/country_list_en.php. [Accessed: 21-Mar-2015].

[4] Ministerio De Minas Y Energía. Memorias al congreso de la republica 2014-2015.

[5] Portafolio.co, El viento ganaría terreno como fuente de energía en el país, 2015.

[Online]. Available: http://www.portafolio.co/print/economia/energia-eolica-colombia-febrero-2015. [Accessed: 31-Aug-2015].

[6] G. E. Valencia Ochoa and M. C. Vanegas Chamorro, *Estudio de la Persistencia Del Viento en la Región Caribe Colombiana con énfasis en La Guajira*, Colombia: Universidad del Atlántico, 2016.

[7] G. E. Valencia Ochoa and M. C. Vanegas Chamorro, *Disponibilidad Geográfica y Temporal de la Energía Solar en la Costa Caribe Colombiana*, Colombia: Universidad del Atlántico, 2016.

[8] G. E. Valencia Ochoa and M. C. Vanegas Chamorro, *Análisis Estadístico de la Velocidad y Dirección del Viento en la Costa Caribe Colombiana con énfasis en La Guajira*, Colombia: Universidad del Atlántico, 2016.

[9] J. Fabregas, G. Valencia and M. Vanegas, Statistical analysis and evaluation of the wind persistence for stations in Departments of La Guajira and San Andrés and Providencia in Colombia, *Rev. Espac.*, **38** (2017), no. 8.

[10] G. E. Valencia Ochoa and M. C. Vanegas Chamorro, *Atlas Solar de la Costa Caribe Colombiana*, Colombia: Universidad del Atlántico, 2016.

[11] G. E. Valencia Ochoa, *Atlas Eólico de la Costa Caribe Colombiana*, Colombia: Universidad del Atlántico, 2016.

[12] K. Koçak, A method for determination of wind speed persistence and its application, *Energy*, **27** (2002), no. 10, 967–973. https://doi.org/10.1016/s0360-5442(02)00033-6

[13] K. Koçak, Practical ways of evaluating wind speed persistence, *Energy*, **33** (2008), no. 1, 65–70. https://doi.org/10.1016/j.energy.2007.07.010

[14] K. Koçak, Examination of persistence properties of wind speed records using detrended fluctuation analysis, *Energy*, **34** (2009), no. 11, 1980–1985. https://doi.org/10.1016/j.energy.2009.08.006

[15] Y. Cancino-Solórzano, A. J. Gutiérrez-Trashorras, and J. Xiberta-Bernat, Analytical methods for wind persistence: Their application in assessing the best site for a wind farm in the State of Veracruz, Mexico, *Renew. Energy*, **35** (2010), no. 12, 2844–2852. https://doi.org/10.1016/j.renene.2010.05.008

[16] Y. Cancino-Solórzano and J. Xiberta-Bernat, Statistical analysis of wind power in the region of Veracruz (Mexico), *Renew. Energy*, **34** (2009), no. 6, 1628–1634. https://doi.org/10.1016/j.renene.2008.11.018

[17] N. Masseran, A. M. Razali, K. Ibrahim and W. Z. Wan Zin, Evaluating the wind speed persistence for several wind stations in Peninsular Malaysia, *Energy*, **37** (2012), no. 1, 649–656. https://doi.org/10.1016/j.energy.2011.10.035

[18] A. Agüera-Pérez, J. C. Palomares-Salas, J. J. González de la Rosa and A. Moreno-Muñoz, Spatial persistence in wind analysis, *J. Wind Eng. Ind. Aerodyn.*, **119** (2013), 48–52. https://doi.org/10.1016/j.jweia.2013.05.011

[19] M. A. Mohandes and S. Rehman, Short term wind speed estimation in Saudi Arabia, *J. Wind Eng. Ind. Aerodyn.*, **128** (2014), 37–53. https://doi.org/10.1016/j.jweia.2014.02.007

[20] Guerra and Weildler, Guajira, Colombia. Bogotá, Colombia, 2003, p 157.

[21] Corpoguajira and Invemar, *Atlas Marino Costero de La Guajira, Serie de Publicaciones Especiales de Invema*. 2012.

[22] M.L. Martín, F. Valero, A. Pascual, J. Sanz, L. Frias, Analysis of wind power productions by means of an analog model, *Atmos. Res.*, **143** (2014), 238–249. https://doi.org/10.1016/j.atmosres.2014.02.012

[23] L. Lu, H. Yang and J. Burnett, Investigation on wind power potential on Hong Kong islands—an analysis of wind power and wind turbine characteristics, *Renew. Energy*, **27** (2002), 1-12. https://doi.org/10.1016/s0960-1481(01)00164-1

[24] M. Villarrubia López, *Ingeniería de la Energía Eólica*, Barcelona, España: Marcombo Ediciones Técnicas, 2012.

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