Article

Journal Economic Development

June, 2023 Vol.10 No.29 16-22

Program for estimating the average wind energy density in a region using 17 methods

Programa para estimación de la densidad de energía promedio del viento en una región mediante 17 métodos

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DOI: 10.35429/JED.2023.29.10.16.22 Received: January 10, 2023; Accepted: June 30, 2023

Abstract

Mexico has an estimated wind potential of 70 GW, however, until 2022 only 7.3 GW were used. This is due, among other factors, to the lack of analysis of the wind resource in many of the country's regions, especially in those where the wind potential is not evident. The lack of automatic meteorological stations (AMS) that measure and record wind speed and direction, as well as the necessary amount of data to make a reliable wind resource estimate, are the main causes of this lack of characterization. Therefore, this article describes the development of a program in Matlab that allows obtaining the average energy density per hour (MEDH) of a region using exact methods and the Weibull probability density function (WPDF) using 15 different methods to determine its parameters C and K. The accuracy of the 15 results obtained from the Weibull PDF is obtained from its comparison with the value obtained from the integration of the power curve and the use of the cube root of the average cubic velocity (Vrmc). The developed application provided the necessary information to evaluate the wind resource of the analyzed region using 16 approximate methods whose error did not exceed 15% and tended to decrease when the data had a Gaussian distribution.

Energy, Power, Wind, Weibull, Analysis

Resumen

México tiene un potencial eólico estimado de 70 GW, sin embargo, hasta el año 2022 solo se aprovechaban 7.3 GW. Esto se debe entre otros factores, a la falta de análisis del recurso eólico en muchas de las regiones del país, especialmente en aquellas donde el potencial eólico no es evidente. La falta de estaciones meteorológicas automáticas (EMA) que midan y registren la velocidad y dirección del viento, así como la cantidad necesaria de datos para realizar una estimación del recurso eólico confiable son las causas principales de esta falta de caracterización. Por lo anterior, en este artículo se describe el desarrollo de un programa en Matlab que permita obtener la densidad de energía medía por hora (DEMH) de una región a partir del uso de métodos exactos y la función de densidad de probabilidad de Weibull (FDPW) utilizando 15 métodos distintos para determinar sus parámetros C y K. La exactitud de los 15 resultados obtenidos a partir de la FDP de Weibull es obtenida a partir de su comparación con el valor obtenido a partir de la integración de la curva de potencia y el uso de la raíz cubica de la velocidad cúbica promedio (Vrmc). La aplicación desarrollada proporcionó la información necesaria para evaluar el recurso eólico de la región analizada empleando 16 métodos aproximados cuyo error no supero el 15% y tendió a disminuir cuando los datos tenían una distribución Gaussiana.

Energía, Potencia, Viento, Weibull, Análisis

Citation: MERAZ-BECERRA, Fernando & CARRILLO-MARTÍNEZ, Jesús María. Program for estimating the average wind energy density in a region using 17 methods. Journal Economic Development. 2023. 10-29: 16-22

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Introduction

In 2022, 73.9% of electricity production in Mexico was from fossil fuel-based generation plants. Combined cycle, conventional thermal, turbogas and coal-fired power plants accounted for 58.1%, 6.3%, 4.6% and 4.3% of this percentage, respectively. While the use of renewable energies such as hydro, wind, solar, nuclear, geothermal and biomass was limited to 10.7%, 6.1%, 4.9%, 3.2%, 1.3% and 0.03%, respectively (CIPP, 2023). Since 2014, the distribution between the use of renewables and oil derivatives had not changed significantly.

To address this problem, Mexico undertook a series of energy, political, economic and social reforms with the aim of enabling the significant introduction of renewable energy power generation systems (Cancino et al., 2011). These reforms were cancelled, however, Mexico will comply with the commitments agreed in the 2015 Paris Convention, generating 35% of electricity from renewable energy by 2030 (Lopez, 2022). Wind energy in Mexico is abundant, has a high energy density, its exploitation is viable and it is widely distributed throughout the territory, which makes it one of the best alternatives for electricity production (Pérez-Denicia et al., 2017).

However, until 2021 in Mexico only 7312 MW of the total wind potential, which has been estimated at around 70 GW (MEP, 2023), was being exploited. This problem is due, among other factors, to the lack of wind resource characterisation in many of the country's regions due to the lack of EMAs that measure and record wind speed and direction, as well as the necessary amount of data to make a reliable estimate. Accurate methods such as power curve integration require the analysis of wind speed recorded every second for at least one year.

Seeking to contribute to the exploitation of the wind resource throughout the country, and especially in those regions with no obvious wind potential, this article describes the development of a Matlab program to obtain the measured energy density per hour (DEMH) of a region from the use of exact methods and the Weibull probability density function (WDPF) using 15 different methods to determine its C and K parameters.

The accuracy of the 15 results obtained from the Weibull PDF is obtained from their comparison with the value obtained from the integration of the power curve and the use of the Vrmc. The program also displays a normalised histogram of wind speeds and compares it with the probability curves obtained from the FDPW. This application requires wind speed and direction data recorded at a height of 10 metres, every 10 minutes, for at least one year.

Theoretical background

The wind energy potential can be estimated from an exact empirical method or by numerical methods that approximate the parameters of interest in the region. The former involves the analysis of the topography of the terrain and its roughness coefficient, the local temperature and pressure and the wind speed to obtain the mechanical wind power which in conjunction with its direction will determine the wind energy potential of the wind. The second involves the use of probability density functions (PDF) such as Weibull to estimate the wind behaviour and thus the wind potential of the region.

Instantaneous power in the wind

The kinetic energy in air of mass m moving with velocity V, is (Patel, 2006):

$$Ec = \frac{1}{2}\, m\, V^2 \qquad (1)$$

The power available in a free air stream is the flow of kinetic energy per unit time through the cross-sectional area of the rotor blade of the wind turbine. (Patel, 2006):

$$Pa = \frac{EC}{t} = \frac{1}{2}\frac{m}{t}\, v^2 = \frac{1}{2} M v^2 = \frac{1}{2} \rho\, A\, v^3 \qquad (2)$$

Where P is the instantaneous mechanical power of the wind in motion (w), M is the mass flow rate (Kg/s), ρ is the density of air (Kg/m^3), $A = \pi r^2$ is the area swept by the rotor blades (m^2) and v is the air speed (m/s).

Energy density, wind energy and power coefficient

Power at a location is the power of the wind in a region over a given period of time, measured in Watt * Second. ($W * s$) or Joule (J).

ISSN 2410-4019

According to equation (2) the instantaneous power in the wind is related to the air density, the wind speed and the swept area. In turn, the swept area is directly related to the length of the blades of the wind turbine that would be installed in the studied region if it were found to be technically feasible. This is problematic, because in many cases during the estimation of the wind resource the wind turbine to be used has not yet been chosen, which is why the application developed does not calculate the energy, but rather the energy density expressed in $\frac{J}{m^2}$. For similar reasons, the developed application does not calculate the energy density taking into account the power coefficient since its value also depends directly on the wind turbine to be installed.

Average energy density per second obtained from the integration of the instantaneous power density curve (DEMS_IDPI).

1. The instantaneous power density in the wind (IPD) is calculated from each of the 52560 wind speeds recorded by the EMA every 10 minutes for at least one year in the region of interest, as expressed in equation 7.

$$DPI_i = \frac{1}{2}\rho\, v_i{}^3 Cp \quad (3)$$

Where v_i is the i-th wind speed recorded in the region.

2. The annual instantaneous power density curve of the region of interest is generated.

3. The instantaneous power density curve is numerically integrated with respect to time to obtain the cumulative wind energy density for the year. (DEV_{ANUAL}):

$$DEV_{ANUAL} = \left(\frac{1}{2}DPI_1 + \sum_{i=2}^{n-1} DPI_i + \frac{1}{2}DPI_n\right) \quad (4)$$

It is sometimes necessary to multiply the DEV by a factor T that compensates for the gaps between each discrete measurement recorded by the EMA, typically 10 minutes, so T usually has a value of 10. Equation (9) summarises this.:

$$DEVT_{ANUAL} = \left(\frac{1}{2}DPI_1 + \sum_{i=2}^{n-1} DPI_i + \frac{1}{2}DPI_n\right)T \quad (5)$$

4. Assuming samples are taken every 10 minutes, the units of the$DEVT_{ANUAL}$ are$\frac{W*min}{m^2}$, razs value to be multiplied by 60 in order to obtain in $\frac{W*s}{m^2} = \frac{J}{m^2}$. Finally, the energy density accumulated during the whole year is divided by 31104000. ($1\, year = 365\, days = 8760\, horas = 518400\, minutos = 31104000\, seconds$).

$$DEMS = \frac{DEVT}{31104000}\ \left[\frac{J}{m^2}\right] \quad (6)$$

Hourly average energy density obtained from cube root of mean cubic velocity

Monthly wind speed varies around$\pm$ 30% $a \pm$ 35% above the average wind speed at a typical location during the year (Patel, 2006). Therefore, the wind speed used to determine the power density in (6) should be (Pishgar-Komleh et al., 2014):

$$V_{rmc} = \left(\frac{1}{n}\sum_{i=1}^{n} vi^3\right)^{\frac{1}{3}} \quad (7)$$

Finally, the average energy density extracted from the wind (DEMV) will be obtained in a period that will depend on the quantity and frequency with which the measurements have been made. (Patel, 2006):

$$DEMS = \frac{1}{2}\rho\, V_{rmc}{}^3\ \left[\frac{J}{m^2}\right] \quad (8)$$

Average energy density per second obtained through the Weibull probability density function.

FDP of Weibull

The PDF indicates the probable frequency at which the specified velocity will occur in the study region. The Weibull PDF is given by (Murthy, 2017; Patel, 2006; Ozat & Celiktas, 2016; Wu et al., 2011):

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^k} \quad (9)$$

where v is the wind speed(m/s), $k > 0$ es the form factor (dimensionless) and $c > 0$ is the scaling factor(m/s).

ISSN 2410-4019

Weibull Cumulative Distribution Function

The cumulative distribution function is the accumulation of relative frequency of each wind speed interval, defined by (Murthy, 2017; Patel, 2006; Ozat & Celiktas, 2016; Wouet al., 2011):

$$F(v) = \int_0^v f(v)dv = 1 - e^{-\left(\frac{v}{c}\right)^k} \quad (10)$$

Characteristic Wind Speed Values Using the Weibull PDF

Knowing the Weibull parameters, the root mean cubic velocity, the mean cubic velocity, the most probable wind speed and the highest wind speed can be calculated from equations 17, 18, 19 and 20, respectively. (Justus, 1977; Akdag & Guler, 2015; Christofferson & Gilette, 1987).

$$V_{rmc} = \int_0^{Vmax} v * f(v)\, dv \quad (11)$$

$$V_{rmc}^3 = \int_0^{Vmax} v^3 * f(v)\, dv \quad (12)$$

$$V_{mp} = c\left(1 - \frac{1}{k}\right)^{\frac{1}{k}} \quad (13)$$

$$V_{max} = c\left(1 - \frac{2}{k}\right)^{\frac{1}{k}} \quad (14)$$

Substituting Equation 12 into Equation 8 gives the average energy density per second:

$$DEMS = \frac{1}{2}\rho\, Cp \int_0^{Vmax} v^3 * f(v)\, dv \;\left[\frac{J}{m^2}\right] \quad (15)$$

After some calculations:

$$DEMS = \frac{1}{2}\,\rho\, c^3\, \Gamma\left(\frac{k+3}{k}\right)\;\left[\frac{J}{m^2}\right] \quad (16)$$

Estimation methods for Weibull parameters

Table 1 summarises the formulas corresponding to the 15 methods used to calculate the Weibull c and k parameters, and also gives a general description of the process followed to program them.

Materials and Methods

The development of the application was carried out in the mathematical development platform Matlab 2017a. The program consists of a function that contains the mathematical algorithms to determine DEMS using the three methods mentioned above.

The 15 methods described in Table 1 for calculating the C and K parameters of the FDPW are also encoded in this function. The program also has options to generate graphs relevant to determining a region's wind resource, such as: the wind rose, the normalised histogram of wind occurrence, the normalised distribution of the probability of occurrence of each speed generated from the 15 methods for generating the WTPF, the instantaneous power curve, the graph of wind behaviour and a graph comparing the normalised histogram of wind speed with the 15 curves of probability of occurrence generated from the WTPF, which in this article will serve to demonstrate the accuracy of each method used to determine the parameters of the WTPF.

	Procedure	Mathematical expressions	
		Shape parameter (k)	Scale parameter (c)
STDML (Lysen, 1983)	Simplification of STDMJ to estimate c parameter (38).	$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086}$ (17)	$c = \frac{\bar{v}}{\left(0.568 + \frac{0.433}{K}\right)}$ (43)
STDMJ (Justus et. al,1977) SMOM [17]	1. It requires only the knowledge of the wind mean speed $\bar{v}$ and the standard deviation σ, to estimate k; (15) for STDMJ or (16) for SMOM. 2. In both cases c is determined by (43).	$k = \left(\frac{0.9874\,\bar{v}}{\sigma}\right)^{1.0983}$ (18)	
PWMM (Usta,2016)	1. $\bar{C}$ is calculated from $\bar{v}$ and wind speed values v_i (18). 2. k and c are determined by (17) and (43).	$k = \frac{\ln(2)}{\ln(\bar{C})}$ (19) $\bar{C} = \frac{\bar{v}}{\frac{2}{n(n-1)}\sum_{i=1}^{n} v_i(n-1)}$ (20)	$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)}$ (44)
AMLM (Christofferson & Gilette, 1987)	It requires only the knowledge of the wind speed values v_i, to estimate k (19). C ins obtained from (43).	$k = \frac{\pi}{\sqrt{6}}\left(\frac{n(n-1)}{n\left(\sum_{i=1}^{n}\ln^2(v_i)\right)-\left(\sum_{i=1}^{n}\ln(v_i)\right)^2}\right)^{\frac{1}{2}}$ (21)	
PDM (Akdag & Dinler, 2009)	1. The energy pattern factor (Epf) is calculated from $\bar{v}$ and wind speed values v_i (21). 2. k and c are determined by (20) and (43).	$k = 1 + \frac{3.69}{Epf^2}$ (20) $Epf = \frac{\overline{v^3}}{(\bar{v})^3} = \frac{\frac{1}{n}\sum_{i=1}^{n} vi^3}{\left(\frac{1}{n}\sum_{i=1}^{n} vi\right)^3}$ (22)	
NEPFM (Akdag & Guler, 2015)	1. The Epf is calculated from $\bar{v}$ and v_i values (21). 2. k and c are determined by the following expressions (22 and 44 respectively) and coefficients.	$k = \frac{a4\,Epf^4 + a3\,Epf^3 + a2\,Epf^2 + a1\,Epf + ao}{b4\,Epf^4 + b3\,Epf^3 + b2\,Epf^2 + b1\,Epf + bo}$ (23) $a0 = -0.220374$; $c0 = 0.225761$; $a2 = -5.789610$ $a3 = 2.151430$; $c1 = 0.134704$; $b0 = -1.272850$ $b1 = 3.691150$; $d0 = -0.35144$; $b3 = -0.800468$ $b4 = 0.992007$; $d1 = 0.711818$	$c = \frac{\bar{v}*(k^2 + d1\,k + d0)}{k^2 + c1\,k + c0}$ (45) $c0 = 0.225761$ $c1 = 0.134704$ $d0 = -0.35144$ $d1 = 0.711818$
GM (Jamil et. al, 1995)	1. The wind speed data must be in the form of a frequency distribution. 2. The elements are divided into bins. 3. After some calculations over (10) equation (23) is obtained, which can take the form $y = mx + b$ (24-27). 4. Calculate $\bar{x}$ and $\bar{y}$ by (28) and (29) respectively, and Subsequently k (30) and b (45). 5. Determine c with the calculated values of k and b (46).	$k\ln(v) - k\ln(c) = \ln(-ln[1 - P(v)])$ (24) $y = \ln(-ln[1 - P(v)])$ (25); $x = \ln(v)$ (26); $b = -k\ln(c)$ (27); $m = k$ (28). $\bar{x} = \frac{1}{n}\sum_{i=1}^{N} f_i\, x_i$ (29) $\bar{y} = \frac{1}{n}\sum_{i=1}^{N} f_i y_i$ (30) $k = \frac{\sum_{i=1}^{N}(x_i-\bar{x})(y_i-\bar{y})}{\sum_{i=1}^{N}(x_i-\bar{x})^2}$ (31)	$b = \bar{y} - k\bar{x}$ (46) $c = e^{\left(-\frac{k}{b}\right)}$ (47)
Iterative methods			
MLM (Jhonson & Kotz, 1970)	1. A potential value of k, k_i is determined by (31). 2. If the AE between k and k_i is the required $k = k_i$. 3. After that, c is calculated whit (47).	$k_i = \left(\frac{\sum_{i=1}^{n} v_i^k \ln(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n}\ln(v_i)}{n}\right)^{-1}$ **(32)**	$c = \left(\frac{1}{n}\sum_{i=1}^{n} v_i^k\right)^{\frac{1}{k}}$ **(48)**
MMLM (Mohammadi et. al, 2016)	1. The wind speed data must be in the form of a frequency distribution whit its elements divided into bins. 2. A potential value of k, k_i is determined by the following expression, based on the relative speed frequency in bin i, $f(vi)$, the number of bins, n, and the speed in every bin, v_i (32). 3. If the AE between k and k_i is the required $k = k_i$. 4. After that, c is calculated whit (48).	$k_i = \left(\frac{\sum_{i=1}^{n} v_i^k \ln(v_i) f(v_i)}{\sum_{i=1}^{n} v_i^k f(v_i)} - \frac{\sum_{i=1}^{n}\ln(v_i) f(v_i)}{f(v \geq 0)}\right)^{-1}$ **(33)**	$c = \left(\frac{1}{f(v\geq 0)}\sum_{i=1}^{n} v_i^k f(v_i)\right)^{\frac{1}{k}}$ **(49)**
WAsP (Solyali et. al, 2016)	1. From the actual values of k and c, X should be calculated (33). 2. Equalize equation 34 to zero, and calculate the value of k from a root-finding algorithm like Brent's method. 3. After that, c is calculated whit (43).	$X = e^{\left(-\frac{\bar{v}}{c}\right)^k}$ **(34)** $-\ln(X) = \left(\bar{v} * \left(\frac{\sum_{i=1}^{n} v_i^3}{N\Gamma\left(1+\frac{3}{k}\right)}\right)^{-\frac{1}{3}}\right)^k$ **(35)**	$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)}$ **(44)**
MOM (Arslan et. al, 2014)	1. CV_{MOM} is calculated using wind speed values v_i (35). 2. Different values should be proposed to k_i, to obtain a CV_{MOMi} coefficient (36). 3. If the AE between CV_{MOM} and CV_{MOMi} is the required $k = k_i$. 4. After that, c is calculated whit (43).	$CV_{MOM} = \left[\frac{\left(\sum_{i=1}^{n} {v_i}^2\right)n}{\left(\sum_{i=1}^{n} v_i\right)^2} - 1\right]$ **(36)** $CV_{MOMi} = \left[\frac{\Gamma\left(1+\frac{2}{k_i}\right)}{\Gamma^2\left(1+\frac{1}{k_i}\right)} - 1\right]$ **(37)**	
LMOM (Arslan et. al, 2014)	1. CV_{L-MOM} is calculated using v_i values (37). 2. Different values should be proposed to k_i, to obtain a CV_{L-MOMi} coefficient (38). 3. If the AE between CV_{L-MOM} and CV_{L-MOMi} is the required $k = k_i$. 4. After that, c is calculated whit (43).	$CV_{L-MOM} = \left[\frac{\left(\sum_{i=1}^{n}\left(\frac{i-1}{n-1}\right)v_i\right)\left(\frac{2}{n}\right)}{\left(\sum_{i=1}^{n} v_i\right)\left(\frac{1}{n}\right)} - 1\right]$ **(38)** $CV_{L-MOMi} = \left[1 - [2^{-\left(\frac{1}{k_i}\right)}]\right]$ **(39)**	
MS&SDM (Allouhia et. al, 2017)	1. The relation $\sigma/\bar{v}$ must be calculated. 2. If the AE between the result of (39) and the relation $\sigma/\bar{v}$ is the required $k = k_i$. 3. After that, c is calculated whit (43).	$\frac{\sigma}{\bar{v}} = \frac{\left[\Gamma\left(1+\frac{2}{k}\right)-\Gamma^2\left(1+\frac{1}{k}\right)\right]^{\frac{1}{2}}}{\Gamma\left(1+\frac{1}{k}\right)}$ **(40)**	
EEM (Silva, 2003)	1. The wind speed data must be in the form of a frequency distribution. 2. The elements are divided into bins. 3. CI coefficient is calculated using (43). 4. An approximation error can be determined using (41). 5. When this error is the desired one $k = k_i$. 6. After that, c is calculated whit (49).	$CI = \frac{\left(\overline{v^3}\right)^{\frac{1}{3}}}{\Gamma\left(1+\frac{1}{ki}\right)}$ **(41)** $\sum_{i=1}^{n}\left[W_{vi} - e^{-\left\{\frac{(vi-1)}{CI}\right\}^k} + e^{-\left\{\frac{(vi)}{CI}\right\}^k}\right]^2 = \sum_{i=1}^{n} E_{vi}^2$ **(42)**	

Table 1 Methods for determining the c and k parameters of the Weibull PDF

ISSN 2410-4019

Results

The functionality of the realised programme was tested on the wind speed and direction data recorded every 10 minutes by the EMAs described in table 2

Name	State	Latitude	Length	Year Consulted
Cuatrociénegas	Coahuila de Zaragoza	27.002	-102.073	2022
La Flor	Durango	26.55	-103.99	2022

Table 2 Automatic weather stations consulted

Tables 3 and 4 show the average power density per second for the Cuatrociénegas and La Flor regions, respectively. In all cases, the value obtained from the integration of the power curve (taken as a real reference value), the average quic velocity and the 15 methods from the Weibull PSD are included. Figures 1 and 2 show the comparison of the normalized histogram of wind speed, with the Weibull probability functions generated from the 15 methods to obtain the parameters c and k quoted in table 1 for the Cuatrociénegas and La Flor stations, respectively.

Method		Result [J/m^2]	Error [%]
DEMS_IPI		149.2645	-
DEMS_VRMC		149.3654	0.1
DEMS_FDPW	STDML	231.6817	55.2
	STDMJ	151.2102	1.3
	SMOM	151.9111	1.8
	PDM	148.8199	0.3
	PWMM	149.3654	0.1
	WAsPM	149.3654	0.1
	MLM	156.078	4.6
	MMLM	154.0008	3.2
	NEPFM	149.3668	0.1
	AMLM	154.4457	3.5
	MS&SDM	152.5536	2.2
	LMOM	153.6086	2.9
	MOM	152.5536	2.2
	GM	138.8379	7
	EEM	149.3654	0.1

Table 3 DEMS EMA Cuatrociénegas

Method		Result [J/m^2]	Error [%]
DEMS_IPI		38.6911	-
DEMS_VRMC		36.4533	5.8
DEMS_FDPW	STDML	49.6261	28.3
	STDMJ	34.3731	11.2
	SMOM	34.5805	10.6
	PDM	36.2586	6.3
	PWMM	36.4533	5.8
	WAsPM	36.4533	5.8
	MLM	35.0504	9.4
	MMLM	35.3355	8.7
	NEPFM	36.4479	5.8
	AMLM	34.3804	11.1
	MS&SDM	34.7779	10.1
	LMOM	32.9516	14.8
	MOM	34.7779	10.1
	GM	33.9713	12.2
	EEM	36.4533	5.8

Table 4 DEMS EMA La Flor

Discussion

According to tables 3 and 4, most of the methods for determining the parameters of the Weibull PDF present an acceptable accuracy, with errors lower than 15%. It can be noted in the case of the EMA Cuatrociénegas that 14 of the 15 methods used to calculate the Weibull parameters present an error of less than 3%. The Lysen standard deviation method has an error of 55%.

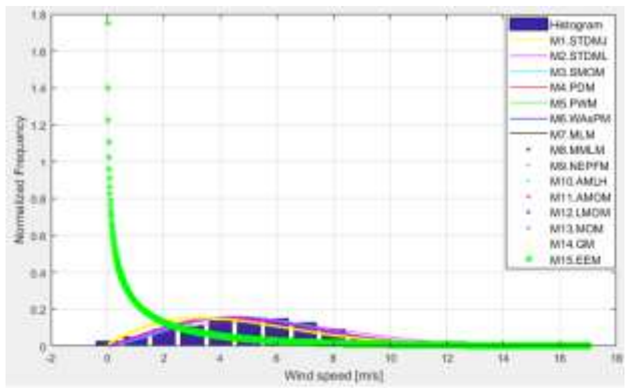

Figure 1 Histogram of the wind occurrence and Weibull probability functions in Cuatrociénegas.

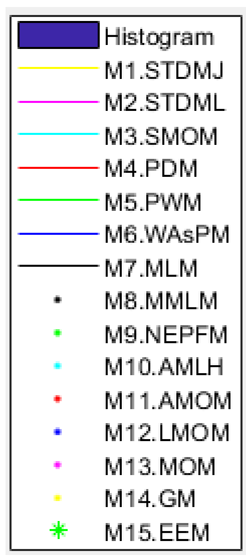

Figure 2 Histogram of wind occurrence and Weibull probability functions at La Flor

The reason why the accuracy of the methods is superior when implemented with the EMA Cuatrociénegas data can be inferred by analysing figures 1 and 2, where it can be observed that the probability curves corresponding to most of the Weibull PDFs fit better to the normalised wind speed histogram when the data distribution resembles a Gaussian distribution with the highest percentage of occurrence positioned in the centre of the curve.

ISSN 2410-4019

It can be seen that specifically the EEM method presents a higher accuracy when the data distribution is not Gaussian.

Conclusion

From the case studies it can be concluded that most of the methods used to approximate the measured energy density represent an acceptable degree of accuracy, especially when the data distribution resembles a Gaussian distribution. During the analysis of different case studies other than those presented in this article, it was possible to detect another factor that has an impact on the accuracy of the methods used to determine the Weibull parameters is data with a multimodal distribution, in which the ranges with the highest percentage of occurrence are separated by ranges with lower frequencies, forming asymmetric data distributions. This type of distribution forms the future work of this research.

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