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Statistical analysis of measured wind speed data's appealing spreadsheet applications

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Abstract. *Once the wind data is measured, the values are processed, based on statistic approach, as accurately as possible, to provide a clear over-view of the locations wind potential, being the basis of any wind farm project, representing the go or no-go in further subsequent design steps. The probability density distributions are derived from time-series data, identifying the associated distributional parameters. The wind energy potential of the locations is studied based on the Rayleigh and Weibull models, implemented with the help of Excel computations, and representing tools, to understand the wind characteristics. Based on the statistical analysis of wind conditions presented here, the results of current study can be used to make a sustainable energy yield for any location.*

Keywords*: wind energy, statistical analysis, Excel, wind data*

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) report published in august 2021, highlights ‚code red' for global heating, driven by human. [1] Measures to counteract, not just trends, but in the meantime a recognized scientific reality, the global heating, are defined at the European Union level in the Green Deal, identifying and fixing targets on different levels focused on no net emissions of greenhouse gases by 2050 and economic growth decoupled from resource use [2]. In increasing the share of renewable energies as well as energy sustainability, the wind energy, will have a significant role. [3]

Once the technologies enable to build bigger wind turbines (higher pills, larger rotor diameter and consequently more installed power per wind turbine), locations that until now were not suitable for exploiting the wind potential, even under certain subsidy conditions, can become now interesting.

The character of this energy source is a stochastic one, the most important parameter, the wind speed, and his direction, are, for a given location, mostly randomly in time. Wind data analysis and accurate wind energy potential assessment are critical factors for suitable development of wind power application at a given location.

[4] Knowing the statistical properties of the wind speed is essential for computing parameters which describe the potential of a location, independent of the wind turbine characteristic. One such parameter is Wind Power Density (WPD), predicting the energy output of a wind energy conversion system, related to the power characteristic of the turbine. Thus, a proper analysis and understanding of statistical wind speed data are crucial, as well as for the structural and environmental analysis [5] as for the performance of wind energy conversion system [6] and the assessment of the wind energy potential. The probability distribution of wind speeds over a certain time interval correlated with the wind rose, form together the main information needed to estimate, for a given site, the wind energy output.

The main decision of exploiting the wind potential of a certain locations is based on the analysis of measured wind speed data. [7] Mainly, various mathematical tools, focuses on obtaining and subsequent interpretation of the wind speed characteristics, as the *Weibull* or *Rayleigh* functions, simplify the presentation as well the interpretation, of a wide range of wind speed data [4]. Therefore, a lot of software tools have been developed, integrating different features. The presents paper wants to emphasis how applications focused on a spreadsheet, as Excel, can provide a very powerful tool in wind data processing. [8]

2. Wind data – statistical representation and available power

Calculations of energy, and later power, available in the wind is based on physics and geometry knowledge, figure 1. [9]

Starting from the basic definition of the kinetic energy (KE) of an object with mass M and velocity V is given by:

$$KE = \frac{1}{2} M v^2. \tag{1}$$

To find the kinetic energy of the wind, we make the analogy of the air parcel that cross the rotor surface of the wind turbine over a given time with a puck, described through a cross-sectional area (A) and a thickness (D), with a certain volume (Vol). Considering that the density of air volume is given by the report mass per volume, as well as the velocity (v) of the air parcel that can be expressed as the time (T) needed for the air parcel to cross the wind turbine blades, the expression of the kinetic energy gets:

$$KE = \frac{1}{2}(\rho \cdot Vol)v^2 = \frac{1}{2}(\rho \cdot A \cdot D)v^2 = \frac{1}{2}(\rho \cdot A \cdot v \cdot T)v^2 =$$

$$KE = \frac{1}{2}\rho \cdot A \cdot T \cdot v^3 \tag{2}$$

The available power (P) in the air parcel can be expressed dividing energy by time, relation (3), [10] and if afterwards the power expression will be divided with the air parcels cross-sectional area (A), we get the so-called wind power density (WPD), relation (4), a parameter that has no dependence on the wind turbine characteristics:

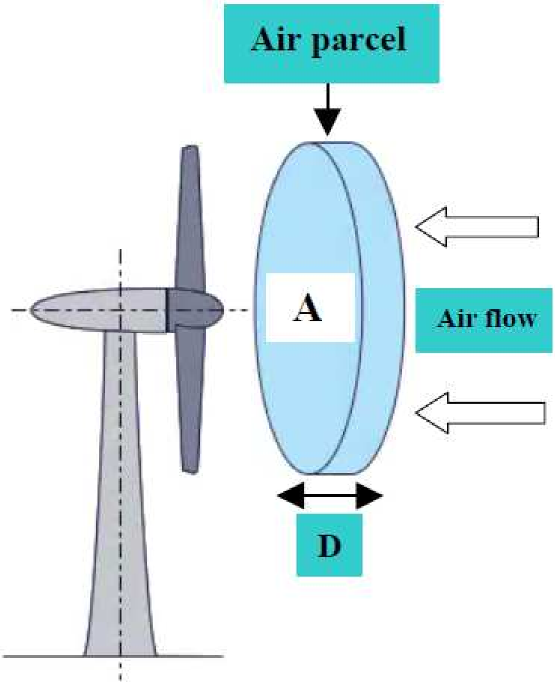

Figure 1. Illustrative for the physics of wind power

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

$$WPD = \frac{1}{2}\rho \cdot v^3 \tag{4}$$

Generally, the locations that fits for exploitation of the wind potential, are priority described based on the *wind class* ranking rather mean wind speed or wind power density (WPD), the wind power classes, seven in number, being associated with a variation range of the WPD.

The usual method of obtaining the frequencies of different speeds is classification. The measured speed values (i.e. the values averaged over a period of 1 or 10 minutes) are divided into classes of 1 m/s and displayed as a frequency distribution. These metrologically recorded relative frequency distributions can be described analytically by the two-parametric Weibull distribution with the shape parameter k and the scaling factor A, figure 2. [10] The shape of the Weibull curve is described by the shape parameter k taking usually values between 1 and 3. Figure 3 shows curves of the Weibull function for different shape parameters at an average wind speed of 4 m / s. [4]

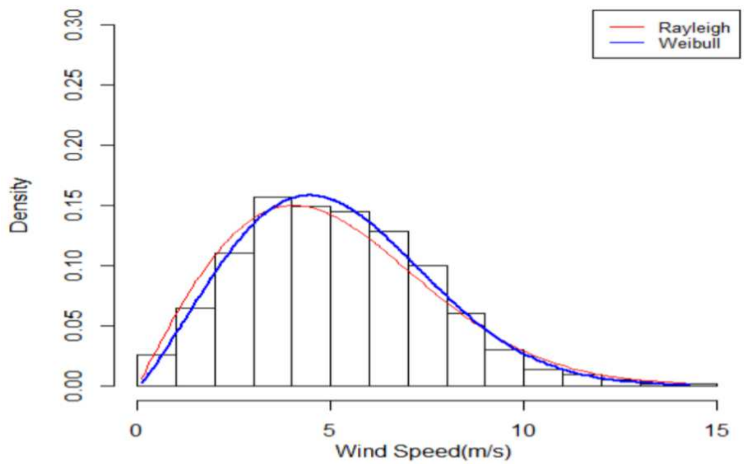

Figure 2. Example of a frequency distribution fitted with Weibull and Rayleigh curves [10]

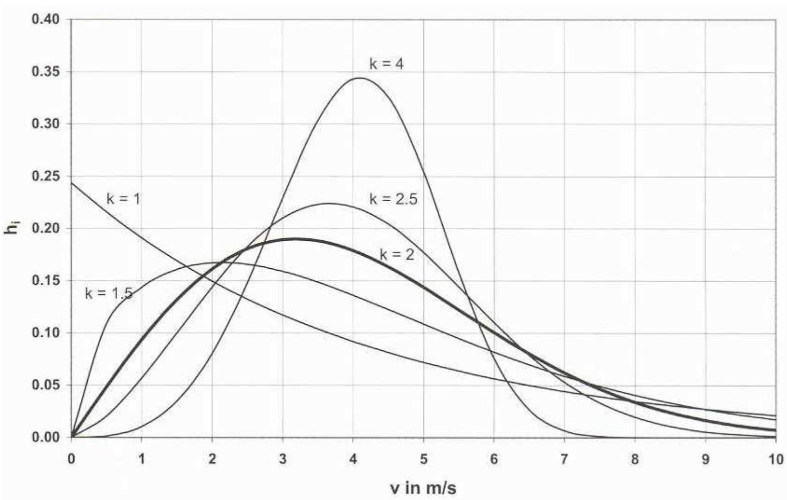

Figure 3. Wind speed distribution based on the Weibull function for a mean wind speed v=4 m/s; k=2 Rayleigh distribution

As an important parameter in computing more exactly the wind potential for each location intervenes the air density, ρ, that depends on a series of factors, as:

elevation above sea level, atmospheric pressure, air temperature. To obtain a first overview of the location's possibility of wind exploitation, the use of ρ= 1.225 kg/m^3 is widespread, which does not lead to huge error in the WPD estimation process. [10]

The WPD expression (4) contains the assumption of computing it considering the mean wind speed, but to obtain a more accurate estimation of WPD, must be done a summation over time, as follows

$$WPD = 0.5 \cdot \frac{1}{n} \sum_{i=1}^{n} (\rho_i \cdot v_i^3), \tag{5}$$

were n representing the wind speed readings, v_i and ρ_i are the j^{th} (1st, 2nd, 3rd, etc.) readings of wind speed and air density. [11] The most accurate result, since wind speed v and air density ρ will change with every new measurement, would entail a calculation for every data interval. The WPD can be interpreted as if an energy source with this determined average power would be constantly available at the considered location and in the considered period. [10]

3. Statistical analysis on given wind data set, using Microsoft Excel spreadsheet applications

The provided analysis we will use wind date measured for a year [12], consisting of wind speed related to hours per year. Based on that information, *Excel* gives us the opportunity to create a histogram from the wind data. [13] For this we will compute the percentage of the time/hours the wind blows with a certain wind class related to the analyzed time (one year) by dividing each position in the *Hours per year* column to the total sum (8760 hours = 1 year), obtaining the frequency of occurrence. To represent the histogram, we select and represent the first, *A*, and third, *C*, column (figure 4) in a graph, for which the bar chart fits best, figure 5.

If we want to compute the *Weibull Density Function*, Excel has for this the WEIBULL.DIST(x, alpha, beta,cumulative) [14] function, were, in our case, x represents the wind speed, alpha – the shape factor, usually know as *k* for which we will use the value two, beta what we know as lambda, for what we will use 7, and then we are asked rather we want to keep a cumulative distribution function, TRUE, or a probability density function, FALSE, that we will use: WEIBULL.DIST(A3, 2, 7, FALSE). Summing all the computed range of values, we obtain a value close to one (≈ 1.01). Plotting the two columns, *A* and *D*, figure 4, we obtain what is expected to be a Weibull curve, figure 6.

Next, we will look at the power in the wind, comparing it using the annual average speed (4) versus using the wind distribution (5). If we compute and use the medium wind speed for the given wind data, figure 4 Column F, the resulted WPD is 226.28 W/m^2, figure 4 Column E. If we multiply this value with the number of hours per year, 8.760 *h*, we obtain 1982204.53 Wh/m^2, representing the total power per unit area, as an average, that will go through at that given site for the average wind speed of the location. If we do now the same but for each of our bins, and sum the column H, figure 4, we obtain 383.56 W/m^2, which multiplied by the total number of hours per year, will lead us to 3359999.33 Wh/m^2. The proportion between W/m^2 and Wh/m^2 are similar, 383.56 W/m^2 / 226.28 W/m^2 ≈ 1.7, that means we obtain almost twice as much power out per unit area using the Weibull distribution! This reflects what really happens with the evolution of the wind, rather than the situation with a constant speed value (average wind speed).

	A	B	C	D	E	F	G	H
2	**Bin / wind speed (m/s)**	**Hours per year**	**Frequency of occurrence**	**Weibull Probability Density Function**	**Product (A x B)**	**Medium wind speed**	**WPD with medium wind speed**	**Power in the Wind**
3	0.5	47	0.0053653	0.020304305	23.5	**7.1753995**	**226.2791**	0.0004
4	1	181	0.0206621	0.039991783	181			0.0124
5	2	434	0.0495434	0.075233506	868			0.23781
6	3	582	0.0664384	0.101902959	1746			1.0763
7	4	753	0.0859589	0.117783231	3012			3.30082
8	5	903	0.1030822	0.12252511	4515			7.73116
9	6	1037	0.118379	0.117465862	6222			15.3419
10	7	1058	0.1207763	0.105108412	7406			24.8558
11	8	954	0.1089041	0.088446801	7632			33.4553
12	9	781	0.0891553	0.07033331	7029			38.9965
13	10	613	0.0699772	0.053029636	6130			41.9863
14	11	460	0.0525114	0.038000134	5060			41.9356
15	12	330	0.0376712	0.025925144	3960			39.0575
16	13	235	0.0268265	0.016861821	3055			35.3627
17	14	153	0.0174658	0.010466079	2142			28.7556
18	15	101	0.0115297	0.006204629	1515			23.3476
19	16	61	0.0069635	0.003515498	976			17.1134
20	17	35	0.0039954	0.001904722	595			11.7777
21	18	21	0.0023973	0.00098729	378			8.38849
22	19	12	0.0013699	0.000489767	228			5.63753
23	20	6	0.0006849	0.000232596	120			3.28767
24	21	3	0.0003425	0.00010578	63			1.90295
25	22	0	0	4.60777E-05	0			0
26	23	0	0	1.92289E-05	0			0
27	24	0	0	7.68899E-06	0			0
28	25	0	0	2.94648E-06	0			0
29								
30	Total	**8760**	**1**	**1.016894317**				**383.562**

Sheet1

Figure 4. Analyzed wind data in Excel

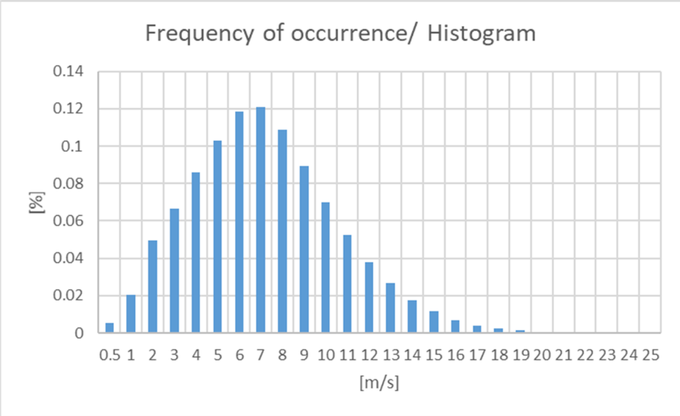

Figure 5. Histogram of wind data in Excel

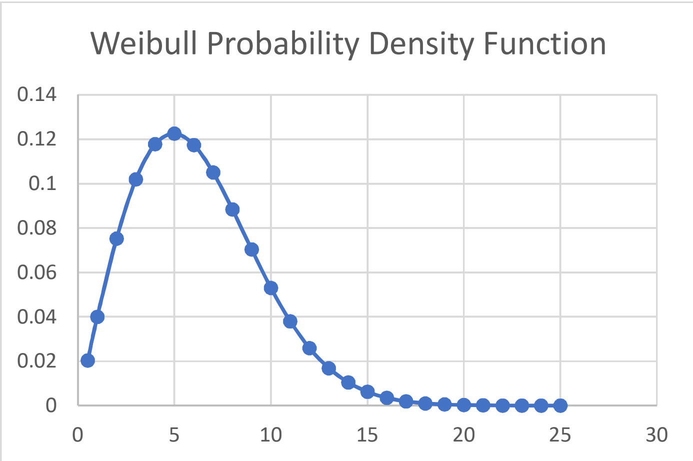

Figure 6. Weibull distribution

4. Conclusion

The paper reflects a part of the main statistical analysis that can be applied on measured wind data appealing spreadsheet applications, in this case *Microsoft Excel*. The statistical computation on the wind speed datas have showed a high level of transparency for the user, being able to follow and understand much better the entire computational steps, the existing connections and interaction between certain parameters, and, as well, the big advantage of not having to resort on specialized developed programs, which requires acquisition fee, and, usually, additional maintenance costs.

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