ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
https://doi.org/10.17559/TV-20230925000961
Original scientific paper

Wind Energy Potential for the Electricity Generation in the Livno Area

Rejhana BLAŽEVIĆ*, Halima HADŽIAHMETOVIĆ

Abstract: Energy consumption in Bosnia and Herzegovina is constantly increasing, and such a trend is expected in the future. By international agreements, Bosnia and Herzegovina has committed itself to the implementation of decarbonization by 2050. This means that by then it should increase its share of energy from renewable sources, and by 2030 to over 40%. Bosnia and Herzegovina has a huge potential for the production of electricity from renewable sources, especially wind and solar energy. In this research, an analysis of the basic characteristics of the wind was performed in order to determine the energy resource of the wind at a given location and the possibility of electricity production. Measured data of wind velocities and wind directions for the time period from 1 January to the end of 2020, obtained from the Federal Hydrometeorological Institute of Bosnia and Herzegovina, were used for the analysis of wind potential in the Livno area. To determine Weibull's parameters, graphical method also known as Least Squares method (LSM) was used. The results of this investigation showed that wind energy in the analysed place can be used for the operation of small wind power plants, which have operating characteristics very similar to larger wind power plants, but the required wind speed for the production of electricity is significantly lower. For a more precise estimation of wind potential, it is necessary to perform measurements at several measuring locations in a small geographical area and in a longer time period.

Keywords: graphical method; Weibull parameters; wind resource; wind velocity; wind velocity distribution

1 INTRODUCTION

The concept of sustainable development as well as the need to use renewable and clean energy sources are increasingly present today due to the increasing energy consumption as well as the desire to preserve the environment. Wind and solar energy, as one of the forms of renewable energy sources, represent the fastest growing energy technologies. The reason for this is partly the significant drop in investment prices, the global decarbonization of the energy system, the encouragement of the use of clean energy primarily from renewable sources by the European energy policy, and the requirements to reduce greenhouse gas emissions [1]. During 2021 almost 94 GW of new wind power capacity was installed worldwide. That represents only 1,8% less capacity than the record year 2020. In the new wind power capacities installed during 2021. year, China participates with over 50%, the USA participates with 13,5%, Brazil and Vietnam with about 4% each, while the rest of the world with about 25%. Total installed wind capacity in 2021. was 837 GW, with a recorded growth of 12,4% compared to 2020 [2]. Considering that global installed wind capacity is constantly increasing, there are many studies and researches which have been performed to evaluating of wind energy resources in different regions. Köse and Güneşer [3] investigated potential of wind energy of seven cities in Turkey. Genç and Gökçek [4] studied the possible wind energy potential and wind characteristic in Kayseri, Turkey, using the hourly wind velocities data for the six years period. In addition, Blazevic et al. [5, 6] investigated wind potential in Sarajevo by analysing wind velocities data for the ten years period. Several studies compared different methods for calculating the shape and scale parameters of the Weibull distribution. P. K. Chaurasiya et al. [7] compared results obtained by using nine methods for determining the Weibull parameters for calculating wind power density. Their results indicated that the maximum likelihood method is more effective Weibull parameter estimation method than other methods. A. H. Shaban, A. K. Resen and N. Bassil [8] in their research also evaluated Weibull parameters by different methods, with the goal to find a precise method for modelling the power of wind farm by the Weibull distribution. They used various statistical tests to measure the performance of the considered methods. The authors have concluded that the equivalent energy method is the most accurate method for calculating Weibull parameters. Also, Kang et al. [9] reviewed six numerical methods used for the estimation of the Weibull parameters. For the estimation, they used measured wind velocity data from nine sites for the period of five years. The results showed that at the moment the method was the most accurate for all topographical conditions, while the graphical method performed the worst. Hussain at al. [10] provided a comparative analysis of eight numerical methods to calculate parameters of the Weibull distribution function to estimate wind power density in four different coastal regions of Pakistan. Zaheer F. et al. [11] proposed a new method for calculating the Weibull parameters. This new method is based on a cumulative distribution function and MATLAB is used for simulation. They have achieved a better fit by using the newly proposed method. Aziz et al. [12] investigated the influence of different methods of determining Weibull parameters on the accuracy of wind potential estimation. In that purpose, they comparatively analysed fourteen methods of determining Weibull parameters which were compared by statistical analyses. Based on the obtained results, they concluded that the most suitable method for the determination of the Weibull parameters was the energy pattern factor method. Several works in literature analysed possibility for installation of micro and small wind turbines in urban areas. In that regard, M. Pellegrini, A. Guzzini and C. Saccani [13] showed a methodology for evaluation of the economic profitability of micro-wind turbine at urban areas. The obtained results showed that the installation of micro-wind turbines is not sustainable in areas with very low average annual wind velocity. A. I. Idriss et al. [14] analysed wind energy resources at Djibouti-city using measured wind velocity data for five years period. The results showed that analysed location has a potential for developing the small wind turbines for domestic applications. According to previously conducted research, it has been shown that Bosnia and Herzegovina has significant potential of renewable energy sources. This especially applies to hydropower, wind power and biomass. However, hydroelectric and thermal power plants dominate in the production of primary energy. Over 60% of the country's energy hails from fossil fuels, primarily coal, hydropower provided about 36% of the country's total electricity production while solar and wind power plants represent a small percentage of the overall energy mix at about 4% [15]. Bosnia and Herzegovina currently has three wind farms, where one of them is in Podveležje and two are in the area of Tomislavgrad. Fig. 3 shows the distribution of electricity generation in Bosnia and Herzegovina in 2022. From Fig. 1, it can be seen that coal is the most used source for electricity production in Bosnia and Herzegovina and almost two thirds of total electricity generation were sourced from lignite coal. Hydropower, with 35% of generation, was the second leading source of electricity production in the country that year.

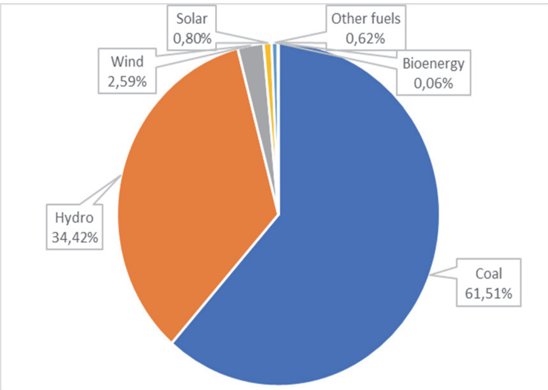

Figure 1 Distribution of electricity generation in Bosnia and Herzegovina in 2022 [15]

According to previous research, the area of Herzegovina has the greatest potential for the construction of wind power plants in Bosnia and Herzegovina. Based on a study by an International Renewable Energy Agency (IRENA), the profitable potential for the construction of wind farms is 10,619 MW, and the potential production of electricity is 22,893 GWh [16]. For the purpose of comparison, the total consumption of electricity in 2020 was only 16874 GWh, which is less than the potential production of electricity using wind power [17]. The main objective of this study is to analyse resources of wind energy for the purpose of power production in the Livno area. Ten-minute data of wind velocity and wind direction in the area of Livno obtained for 2020 were used to calculate the mean monthly and annual wind velocity values, as well as the mean wind power density. Frequency distribution of the wind velocity was described by Weibull distribution while the Weibull parameters were determined using graphical method for two different heights, the height of wind velocity measurement and the hub height. Methodology for calculation is presented and the conclusions are highlighted at the end.

2 LOCATION AND WIND DATA

The weather station Livno is located in the city of the same name in the west of Bosnia and Herzegovina. Meteorological station Livno is located at 43°49'22" latitude and 17°00'04" longitude. It is located at 723 meters above sea level. The measuring device is placed 23 m above the ground, so the measuring anemometer is located at a total of 746 meters above sea level. The meteorological station Livno started operating in 1893 and continuously measures all important meteorological phenomena. Wind data at the Livno meteorological station were measured in ten minutes terms. As already mentioned, the region of Livno is a potentially suitable area for the construction of wind farms. However, this meteorological station is located in an urban environment, so the indicators of parameter measurements may not be reliable for the entire, i.e. wider region (due to city buildings that create obstacles to the flow of wind), but they can be useful in examining wind potential, and in researching potential new locations in the immediate and wider surroundings of the city. For visualization purposes, Fig. 2 and 3 show the wind atlas for the area of Bosnia and Herzegovina with the mean annual wind velocity at a height of 100 m where can be seen the micro location and macro location of the meteorological station Livno.

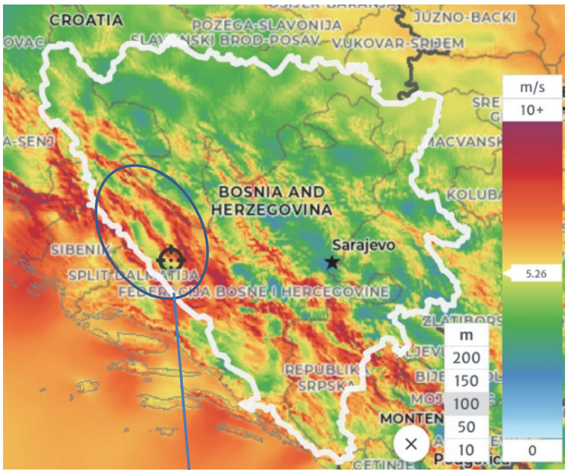

Figure 2 Mean wind velocity in Bosnia and Herzegovina at 100 m height with micro location of Livno [18]

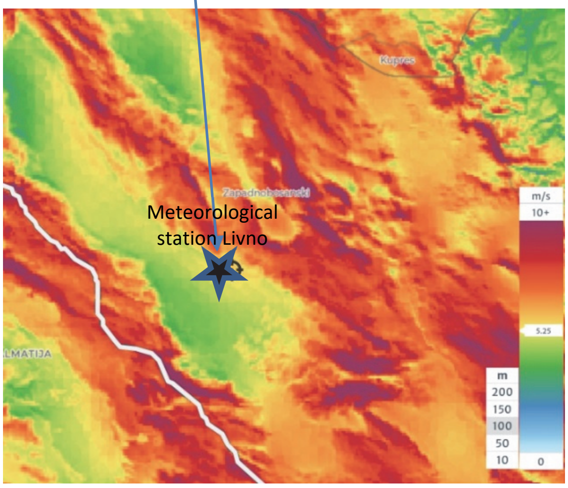

Figure 3 Mean wind velocity in Bosnia and Herzegovina at 100 m height with macro location of Livno [18]

The measurement of wind characteristics in Bosnia and Herzegovina has been carried out for many years, on the basis of which it was estimated that the southern part of Bosnia and Herzegovina has the highest wind potential; however, the first measurements with adequate equipment for determining the wind potential began in 2002 in Mostar at the Sveta Gora - Podveležje location. The main goal of this investigation is to analyse wind velocity distribution for one-year period in the area of Livno for the purpose of electricity production.

3 METHODOLOGY

3.1 Indicators of Wind Energy Resources

The mean wind velocity value, as one of the basic characteristics of wind, can be calculated using Eq. (1) [19-21]:

$$v_m = \frac{1}{T}\int_0^T v_t\left(t\right)\mathrm{d}t \tag{1}$$

where v_t is current wind velocity in m/s and T is the time interval in which the mean wind velocity is calculated.

The obtained measured data on wind velocity, used for the analysis in this paper, refer to the height h_1 = 23 m, which is the height at which the measuring device is installed at the meteorological station. Since that height is different from the hub height it is necessary to calculate the change in wind velocity with height. In this case, the power law was used for that calculation according to the Eq. (2) [19, 23]:

$$v_{hub} = v_1\left(\frac{h_{hub}}{h_1}\right)^a \tag{2}$$

where v_1 is wind velocity in m/s at height h_1 above the ground in m/s, v_{hub} is the wind velocity m/sat hub height h_{hub} and α is the power law exponent primarily dependent on the surface roughness of the terrain. Since the meteorological station Livno is located in urban area, in this research it is assumed that power law exponent has a value of 0,4 [24, 25].

The wind power density, calculated by measured data, which is a function of the cube of wind velocity can be expressed as the following [19, 25-27]:

$$\frac{P}{A} = \frac{1}{2}\rho_m\left(v^3\right)_m \tag{3}$$

where P represents wind power in W, A is area in m^2, ρ_m is air density value which depends on altitude (in this paper a constant value of the air density is assumed as 1,225 kg/m^3), $(v^3)_m$ is the the mean value of the third power of the wind velocity.

The variation of wind velocity in a certain area is commonly described by the Weibull distribution function. Probability density function (PDF) and cumulative distribution function (CDF) as a function of wind velocity v are given as follows [27-30]:

$$f\left(v\right) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1}\cdot e^{-\left(\frac{v}{c}\right)^k} \tag{4}$$

$$F\left(v\right) = \int_0^v f\left(v\right)dv = 1 - e^{-\left(\frac{v}{c}\right)^k} \tag{5}$$

where v is wind velocity, k is the dimensionless shape factor, and c is the Weibull scale factor in m/s.

Considering that the Weibull parameters strongly influence the distribution, many methods have been developed for their most accurate calculation. For determining the scale factor and the shape factor the graphical method will be used in this paper.

3.2 Graphical Method (GM) for Estimating Weibull parameters

The graphical method is also known as linear least square method because it uses a linear least-squares regression in calculation. By applying a double logarithmic transformation to the expression (5), the cumulative distribution function could be transformed into a linear function expressed by relation [28, 31, 32]:

$$\ln\left\{\ln\left[1/\left(1-F\left(v\right)\right)\right]\right\} = k\ln\left(v\right) - k\ln\left(c\right) \tag{6}$$

where the shape and scale parameter are defined by slope and intercept on the ordinate of the obtained linear function. By introducing the following shifts: $y = \ln\left\{\ln\left[1/\left(1-F\left(v\right)\right)\right]\right\}$, $x = \ln v$, $B = k$, $A = -k\ln\left(c\right)$. Eq. (6) takes the following form:

$$y = Bx + A \tag{7}$$

where y or $\ln\left\{\ln\left[1/\left(1-F\left(v\right)\right)\right]\right\}$ is the ordinate and represents dependent variable ony-axis, x or ln$v$ is abscissa which represents independent variablex-axis, B denotes the slope and A or $-k$ln(c) is intercept. Finally, the Weibull parameters can be calculated according to the following expressions:

$$k = B, \text{ and } c = e^{-\frac{A}{B}} \tag{8}$$

4 RESULTS AND DISCUSSION

One of the most influential parameters in the analysis of wind energy resources is wind velocity. Fig. 4 and 5 show the variation of mean ten-minute wind velocity during one-year period as well as the daily wind velocity values in the same period. The maximum value of the wind velocity that appeared throughout the measurements in the considered period was 12,2 m/s, and the lowest was 0 m/s (without wind), while the average annual wind velocity was about 2 m/s. Fluctuations in wind velocities are less noticeable in the range from 0 m/s to 4 m/s.

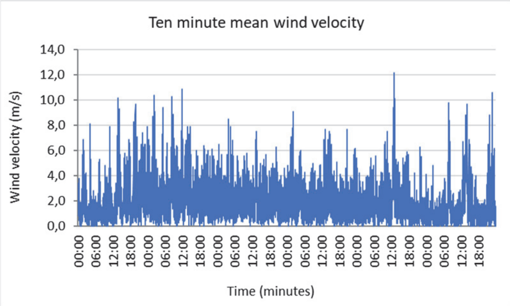

Figure 4 Ten-minute wind velocity variation for 2020

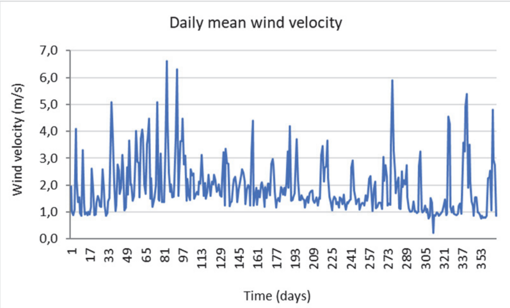

Figure 5 Daily wind velocity variation for 2020

Considering that the wind is not a phenomenon of a constant nature, the mean value of the velocity for the analysed location cannot be a reliable indicator of the value of the energy that the wind turbine can produce. At higher wind velocities, a greater amount of energy is obtained. That is why it is necessary to analyse how long the wind of a certain velocity and direction acts at a given location. This information, together with the specified power curve of a certain wind turbine, enables the calculation of the energy production for a given time period. There are different graphic interpretations of the wind rose, which describe the frequency of occurrence of wind from a certain direction. The shape of the wind rose is different for each station and depends on the orography of the terrain. The wind frequency rose and the mean wind velocity rose for the weather station Livno for 2020 are shown in Fig. 6 and Fig. 7. From Fig. 6 and Fig. 7 it can be seen that the prevailing wind directions are south-east (SE) in 9,6% of cases with the calculated wind velocity of 1,8 m/s, then east-southeast (ESE) and south-southeast (SSE) with an occurrence share of about 9% and with calculated wind velocity of 1,2 and 2,3 m/s, respectively.

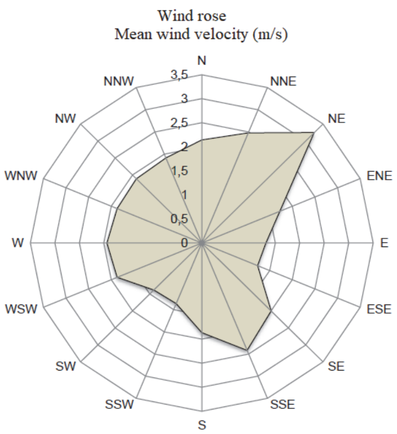

Figure 6 Wind rose for meteorological station Livno for 2020 with mean velocity of individual wind directions

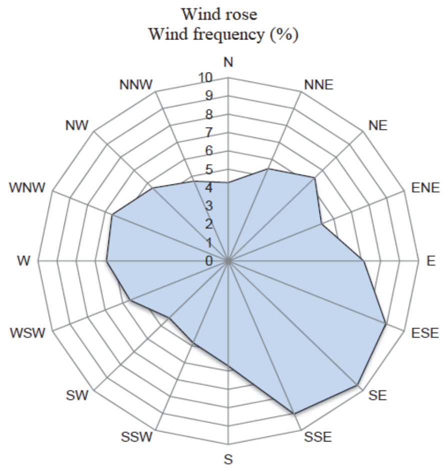

Figure 7 Wind rose for meteorological station Livno for 2020 with frequency of individual wind directions

As one of the indicators of wind energy resources, wind velocities data were used to assess the wind power density in the Livno area. Fig. 8 and Fig. 9 show the variations in the mean wind power densities and mean wind velocities by month during 2020 at two different heights. As it can be seen from Fig. 8 and Fig. 9, wind velocities and wind power densities vary significantly from month to month. The minimum value of power density was calculated for November, and the highest value of power density occurs in March, which is a direct consequence of the wind velocity. The maximum wind velocity occurred in March with value 2,7 m/s, while the minimum wind velocity was in November and its value was 1,24 m/s.

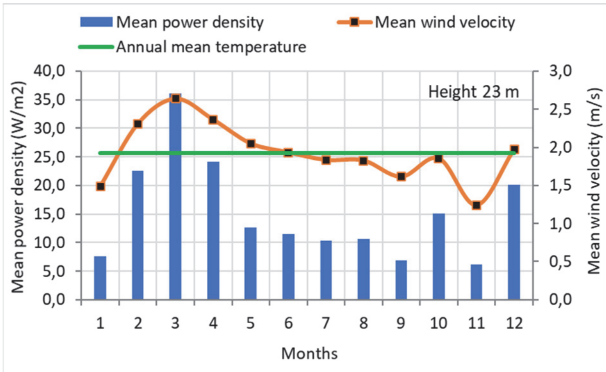

Figure 8 Monthly mean wind velocity and mean power density variations at 23 m height during 2020

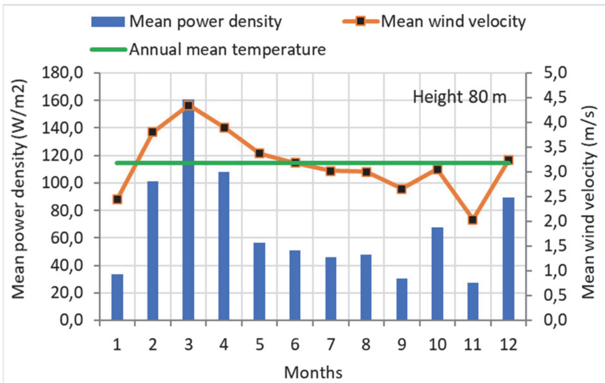

Figure 9 Monthly variation of mean wind velocity and mean power density at 80 m height

The statistical data of wind velocity in Livno at a height of 23 m above the ground needed for determining Weibull parameters using graphical method are presented in Tab. 1.

Table 1 Statistical data of wind velocity in Livno at 23 m height

Range	Wind velocity v / m/s	Number of occurrences T / hours/year	Frequency	Cumulative frequency	ln(v)	ln[–ln[1–F(v)]]
0	0	47	0,00529	0,00529	-	–5,23858
0-1	1	2763	0,31457	0,31986	0,00000	–0,95332
1-2	2	3089	0,35168	0,67154	0,69315	0,10737
2-3	3	1288	0,14659	0,81814	1,09861	0,53327
3-4	4	765	0,08705	0,90519	1,38629	0,85690
4-5	5	433	0,04924	0,95442	1,60944	1,12765
5-6	6	207	0,02360	0,97803	1,79176	1,33973
6-7	7	96	0,01087	0,98890	1,94591	1,50426
7-8	8	59	0,00670	0,99560	2,07944	1,69115
8-9	9	27	0,00302	0,99861	2,19722	1,88434
9-10	10	9	0,00102	0,99964	2,30259	2,07040
10-11	11	3	0,00032	0,99996	2,39790	2,32036
11-12	12	0	0,00002	0,99998	2,48491	2,38623

Following the procedure described for calculating the parameter values k and c using graphical method it is needed to construct the straight least squares according to the data from Tab. 1.

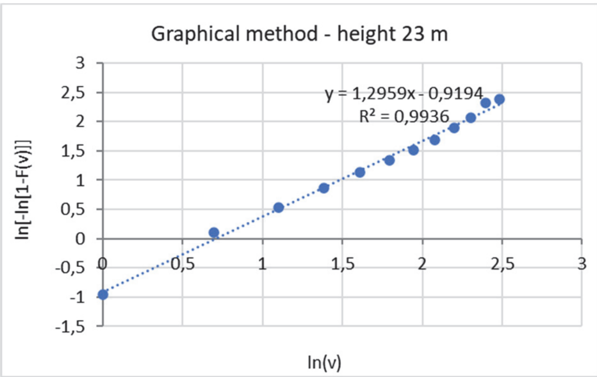

Figure 10 Graphical method for estimating Weibull parameters at 23 m height

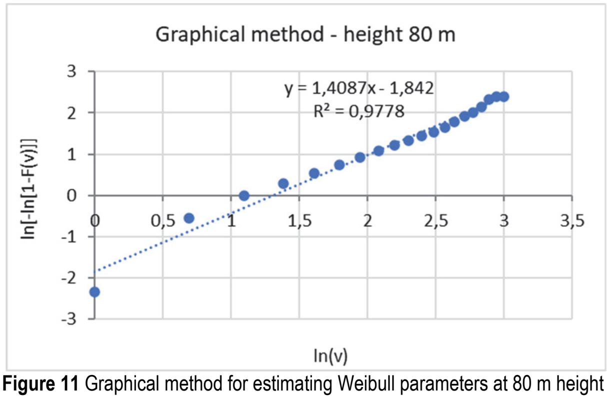

Figure 11 Graphical method for estimating Weibull parameters at 80 m height

From Fig. 10, it can be seen that the sketched points from the sample are close to the drawn line and this means that the model describes the phenomenon well. The equation of the straight line drawn through the points from the sample for a height of 23 m is:

$$y = 1,2959x - 0,9194 \quad (9)$$

Thus, based on the Eq. (7) and (8) Weibull parameters for height 23 m can be determined as k = 1,2959 and c = 2,0329. From Fig. 11, Weibull parameters for height 80 m can be determined in the same way, where with the slope of the linear regression curve of 1,4087 and the intercept of-1,842, the following values k = 1,4087 and c = 3,697 are obtained. Fig. 12 and Fig. 13 represent the scatter plot and polynomial fit of the monthly mean wind power density on the dependent axis versus mean wind velocity along the independent axis for two different heights. The relationship between mean wind power density and mean wind velocity is shown by the second-order polynomial function. The coefficient of determination R^2 was found to be 0,924. This means that almost 92,4% of the input time series data is covered and well fitted on the regression plot.

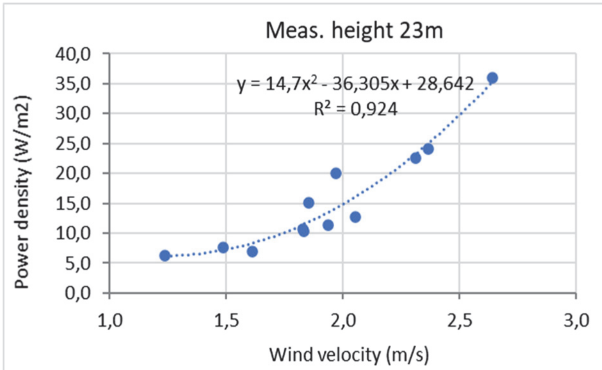

Figure 12 Relationship between monthly mean wind power density versus monthly mean velocity with polynomial fit at 23 m height

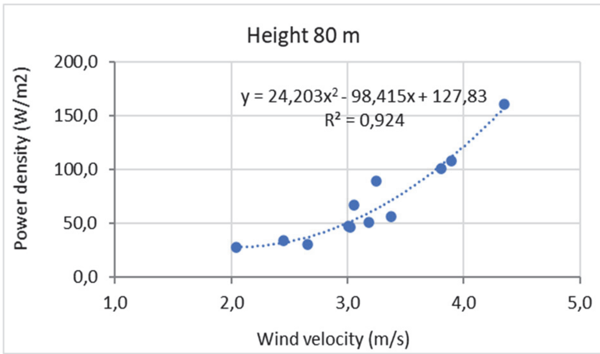

Figure 13 Relationship between monthly mean wind power density versus monthly mean velocity with polynomial fit at 80 m height

To accurately estimate available wind power, knowing only wind velocity and direction is insufficient. The final analysis should be presented through a histogram, illustrating the time distribution of wind velocity and the duration of wind at specific velocities at a given location. Fig. 14 and Fig. 15 show the Weibull distribution for two heights above the ground as the most suitable probability distribution where the Weibull parameters were calculated using a graphical method.

According to Fig. 14, the most frequent wind velocity is around 2 m/s, i.e. 35% of the time during the year. The total duration of silence with wind velocity value less than 0,5 m/s was 0,53% for the analysed period.

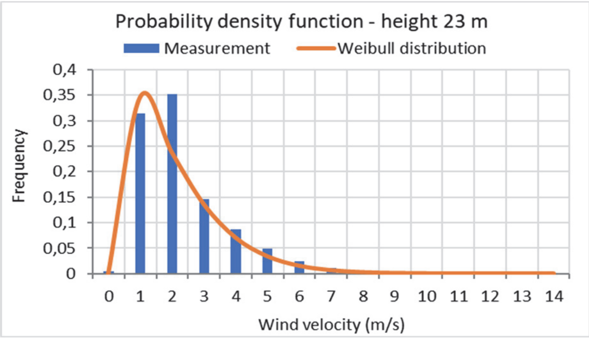

Figure 14 Weibull approximation of the actual yearly wind velocity frequency distribution at 23 m height

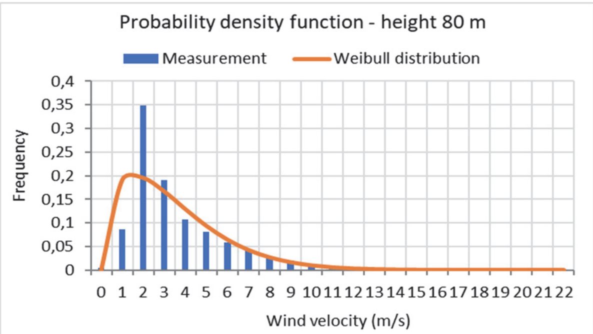

Figure 15 Weibull approximation of the actual yearly wind velocity frequency distribution at 80 m height

Fig. 16 and Fig. 17 show the normalized diagram of the cumulative duration of wind velocities obtained on the basis of one-year measurements of wind velocities in the analysed area at heights of 23 m and 80 m above the ground. From Fig. 16, it can be seen that at a height of 23 m from the ground, more than 60% of the time the wind blows at a velocity of less than 2 m/s, while less than 40% of the time the wind velocity is greater than 2 m/s. From Fig. 17, it can be observed that at a height of 80 m from the ground, about 40% of the time the wind blows at a velocity of less than 2 m/s, while about 53% of the time the wind velocity is less than 3 m/s. At a hub height, which is in this paper at 80 m, the wind velocity is greater than or equal to 3 m/s more than 40% of the time. For micro-wind turbines cut-in wind velocity is about 2,5 m/s [13].

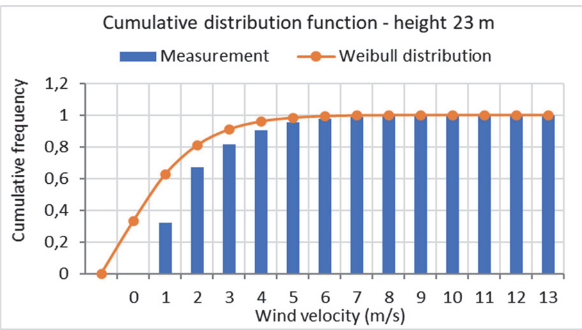

Figure 16 Cumulative distribution function fitted by graphical method and relative cumulative frequency of measured wind velocity at height 23 m

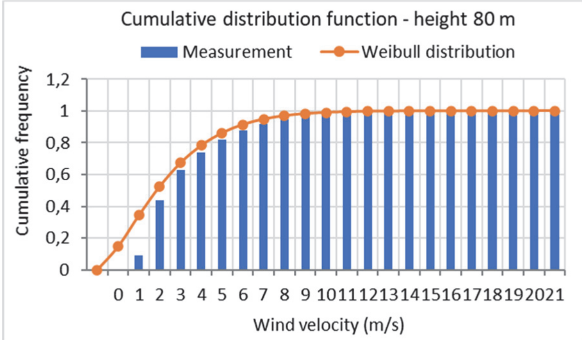

Figure 17 Cumulative distribution function fitted by graphical method and relative cumulative frequency of measured wind velocity at height 80 m

5 CONCLUSIONS AND FURTHER WORK

Based on the conducted analysis, it was concluded that wind energy in the Livno area can be used to operate micro and small wind turbines, which have operating characteristics very similar to larger wind power plants, but require significantly lower wind velocities for electricity production. The cut-in wind velocity for micro-wind turbines is about 2,5 m/s. While the use of wind energy in Bosnia and Herzegovina is primarily based on large wind farms, the development of small wind turbines for households is equally important. These turbines can serve as an additional source of energy to reduce electricity consumption or as a primary energy source, especially in remote areas with limited electricity distribution. The wind energy resources in the Livno area were assessed through statistical analysis of measured wind data at a height of 23 meters over a one-year period. Monthly average wind velocities ranged from 1,24 m/s in November to 2,7 m/s in March at the measurement height, with an annual average of approximately 2 m/s. Prevailing wind directions were identified as south-east (SE) in 9.6% of cases, followed by east-southeast (ESE) and south-southeast (SSE) at around 9% each. To more accurately assess the wind velocity potential at the analyzed location, the wind velocity at a hub height of 80 meters was calculated using the power law. Monthly average wind velocities at the hub height of 80 meters varied from 2,0 m/s in November to 4,3 m/s in March, with an average annual velocity of approximately 3,2 m/s. Statistical analysis utilized Weibull distribution, with shape and scale parameters determined using a graphical method. It is known that a number of factors influence the precise assessment of wind potential. The possible errors in our calculation can be due to anemometer accuracy, a short data collection period which can lead to inaccurate long-term predictions, errors in extrapolating wind velocity data from measurement height to hub height using power law or logarithmic law, and errors in estimating the shape and scale parameters which can affect energy yield predictions. Additionally, ignoring terrain effects can introduce errors, as wind velocity varies with terrain. Considering the very characteristics of the wind and the complexity of the terrain, as is the case in Bosnia and Herzegovina, it is necessary to carry out measurements at several measuring locations within a small geographical area and over as long a time interval as possible. Furthermore, the accuracy of predicting wind potential using calculations decreases at greater distances from the measurement site, especially in the case of complex terrain topography. Therefore, measurements must also be performed at potential locations for the construction of a wind farm. The presented approach in this paper can be generalized for assessing wind energy resources for electricity generation across different areas in Bosnia and Herzegovina, taking into account the variability of different regions due to the diverse terrain and climatic conditions. One of the recommendations for future work is to increase the number of input data. This involves analyzing data on wind velocity and direction over a longer period, with a minimum of 10-minute wind velocity values, to achieve more accurate results for wind energy potential.

6 REFERENCES

[1] Directive 2018/2001 EU (2018) of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. Official Journal of the European Union L 328/82.

[2] Lee, J. & Zhao, F. (2022). *GWEC Global Wind Report 2022*. Global Wind Energy Council: Brussels, Belgium.

[3] Bayram, K. Ö. S. E. & GUNESER, M. T. (2019). Assessment of wind characteristics and wind energy potential in West Black Sea Region of Turkey. *Eskişehir Technical University Journal of Science and Technology A-Applied Sciences and Engineering, 20*(3), 227-237. https://doi.org/10.18038/estubtda.624359

[4] Genç, M. S. & Gökçek, M. (2009). Evaluation of wind characteristics and energy potential in Kayseri, Turkey. *Journal of Energy Engineering, 135*(2), 33-43. https://doi.org/10.1061/(ASCE)0733-9402(2009)135:2(33)

[5] Hadziahmetovic, H., Dzaferovic, E., Ahmovic, I., & Blazevic, R. (2018). Analysis of Wind Velocity Data in the Area of the City of Sarajevo in Period from 2001-2010. *Proceedings of the 29th International DAAAM Symposium 2018, DAAAM Proceedings*, 0250-0259. https://doi.org/10.2507/29th.daaam.proceedings.036

[6] Blazevic, R., Hadžiahmetović, H., & Ahmović, I. (2021). Statistical analysis and assessment of wind energy potential in Sarajevo, Bosnia and Herzegovina. *Tehnički vjesnik, 28*(5), 1511-1518. https://doi.org/10.17559/TV-20200720163605

[7] Chaurasiya, P. K., Ahmed, S., & Warudkar, V. (2018). Study of different parameters estimation methods of Weibull distribution to determine wind power density using ground based Doppler SODAR instrument. *Alexandria Engineering Journal, 57*(4), 2299-2311. https://doi.org/10.1016/j.aej.2017.08.008

[8] Shaban, A. H., Resen, A. K., & Bassil, N. (2020). Weibull parameters evaluation by different methods for windmills farms. *Energy Reports, 6*(3), 188-199. https://doi.org/10.1016/j.egyr.2019.10.037

[9] Kang, D., Ko, K., & Huh, J. (2018). Comparative study of different methods for estimating Weibull parameters: a case study on Jeju Island, South Korea. *Energies, 11*(2), 356. https://doi.org/10.3390/en11020356

[10] Hussain, I., Haider, A., Ullah, Z., Russo, M., Casolino, G. M., & Azeem, B. (2023). Comparative analysis of eight numerical methods using Weibull distribution to estimate wind power density for coastal areas in Pakistan. *Energies, 16*(3), 1515. https://doi.org/10.3390/en16031515

[11] Zaheer, F., Jilani, S. U., Uddin, M. A., Insaf, A., Mamnoon Akhtar, S., & Uddin, Z. (2021). A new approach to assess wind potential. *Global NEST journal, 23*(4), 532-543. https://doi.org/10.30955/gnj.004021

[12] Aziz, A., Tsuanyo, D., Nsouandele, J., Mamate, I., Mouangue, R., & Elé Abiama, P. (2023). Influence of Weibull parameters on the estimation of wind energy potential. *Sustainable Energy Research, 10*(1), 1-18. https://doi.org/10.1186/s40807-023-00075-y

[13] Pellegrini, M., Guzzini, A., & Saccani, C. (2021). Experimental measurements of the performance of a micro-wind turbine located in an urban area. *Energy Reports, 7*, 3922-3934. https://doi.org/10.1016/j.egyr.2021.05.081

[14] Idriss, A. I., Ahmed, R. A., Omar, A. I., Said, R. K., & Akinci, T. C. (2020). Wind energy potential and micro-turbine performance analysis in Djibouti-city, Djibouti. *Engineering Science and Technology, an International Journal, 23*(1), 65-70. https://doi.org/10.1016/j.jestch.2019.06.004

[15] Global Renewable Energy Industry - Statistics & Facts, Report.

[16] The international renewable energy agency.

[17] Agency for statistcs of Bosnia and Herzegovina. (2020). Energy statistics.

[18] Global wind atlas, global solar atlas, energydata.info. *Mean Wind Speed, Bosnia & Herzegovina*. URL: https://globalwindatlas.info/area/Bosnia%20&%20Herzegovina

[19] Mert, I. & Karakuş, C. (2015). A statistical analysis of wind speed data using Burr, generalized gamma, and Weibull distributions in Antakya. *Turkish Journal of Electrical Engineering & Computer Sciences, 23*(6),1571-1586. https://doi.org/10.3906/elk-1402-66

[20] Mostafaeipour, A., Jadidi, M., Mohammadi, K., & Sedaghat, A. (2014). An analysis of wind energy potential and economic evaluation in Zahedan, Iran. *Renewable and sustainable energy reviews, 30*, 641-650. https://doi.org/10.1016/j.rser.2013.11.016

[21] Celik, A. N. (2004). A statistical analysis of wind power density based on the Weibull and Rayleigh models at the southern region of Turkey. *Renewable energy, 29*(4), 593-604. https://doi.org/10.1016/j.renene.2003.07.002

[22] Hensen, J. L. M. (1999). Simulation of building energy and indoor environmental quality-some weather data issues. *Proceedings of the International Workshop on Climate data and their applications in engineering*,1-15.

[23] Ouammi, A., Dagdougui, H., Sacile, R., & Mimet, A. (2010). Monthly and seasonal assessment of wind energy characteristics at four monitored locations in Liguria region (Italy). *Renewable and Sustainable Energy Reviews, 14*(7), 1959-1968. https://doi.org/10.1016/j.rser.2010.04.015

[24] Syngellakis, K. & Traylor, H. (2007). Urban Wind resource assessment in the UK: An introduction to wind resource assessment in the urban environment, Reports No. 2, European Commission.

[25] Manwell, J. F., McGowan, J. G., & Rogers, A. L. (2010). *Wind energy explained: theory, design and application*. John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

[26] Parajuli, A. (2016). A statistical analysis of wind speed and power density based on Weibull and Rayleigh models of Jumla, Nepal. *Energy and Power Engineering, 8*(7), 271-282. https://doi.org/10.4236/epe.2016.87026

[27] Masters, G. M. (2013). *Renewable and efficient electric power systems*. John Wiley & Sons, Inc., Hoboken, New Jersey

[28] Kitaneh, R., Alsamamra, H., & Aljunaidi, A. (2012) Modeling of Wind Energy in Some Areas of Palestine. *Energy Conversion and Management, 62*, 64-69. https://doi.org/10.1016/j.enconman.2012.04.008

[29] Celik, A. (2003) Weibull Representative Compressed Wind Speed Data for Energy and Performance Calculations of Wind Energy Systems. *Energy Conversion and Management, 44*(19), 3057-3072. https://doi.org/10.1016/S0196-8904(03)00075-X

[30] Ulgen, K. & Hepbasli, A. (2002) Determination of Weibull Parameters for Wind Energy Analysis of Izmir, Turky. *International Journal of Energy Research, 26*, 495-506.

https://doi.org/10.1002/er.798

[31] Costa Rocha P. A., Coelho de Sousa R., Freitas de Andrade C., & Vieira da Silva M. (2012). Comparison of seven numerical methods for determining Weibull parameters for wind energy generation in the northeast region of Brazil. *Applied Energy, 89*(1), 395-400. https://doi.org/10.1016/j.apenergy.2011.08.003

[32] Mohammadi, K., Alavi, O., Mostafaeipour, A., Goudarzi, N., & Jalilvand, M. (2016). Assessing different parameters estimation methods of Weibull distribution to compute wind power density. *Energy Conversion and Management, 108*, 322-335. https://doi.org/10.1016/j.enconman.2015.11.015

Contact information:

Rejhana BLAŽEVIĆ, PhD, Associate Professor
(Corresponding author)
Faculty of Mechanical Engineering,
University of Sarajevo,
Vilsonovo šetalište 9, 71000 Sarajevo, Bosnia & Herzegovina
E-mail: muhamedagic@mef.unsa.ba

Halima HADŽIAHMETOVIĆ, PhD, Associate Professor
Faculty of Mechanical Engineering,
University of Sarajevo,
Vilsonovo šetalište 9, 71000 Sarajevo, Bosnia & Herzegovina
E-mail: halima@mef.unsa.ba