EXPLORING WIND PATTERNS AND EVALUATING WIND ENERGY PROSPECTS IN NORTH-WESTERN HUNGARY

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Abstract: This study focuses on assessing wind energy potential in the windiest region of Hungary, near Mosonmagyaróvár. Over a span of 6 years (2010–2015), data on wind speed, direction, and energy production were collected from a wind farm featuring E40 Energon wind turbines. The objective is to enhance weather forecasting by utilizing historical wind data for specifying wind distribution forms. The E40 turbine, positioned at a height of 65 m, exhibits a mean wind speed of 5.26 ± 2.8 m/s with 10-minute time resolution measurements and an average power output of 103 kW (17% of the maximum). The study employs the Weibull distribution to model wind speeds and employs the Power Density method for scale and shape parameter estimation, favouring a computationally efficient approach. Parameters such as scale (k) and shape (c) are derived as functions of mean wind speed, wind sectors, and energy pattern factor. Overall, this research contributes to understanding wind energy viability in the region, considering wind patterns, energy production, and statistical modelling techniques.

Introduction

While the extensive utilization of fossil fuels has been instrumental in driving economic advancement, it concurrently inflicts substantial harm to the environment and contributes to climate change through the escalation of carbon dioxide emissions (Sheffield, 1999). Evidently, global energy consumption, including electricity production, is on the rise (IEA Statistics, 2020). This phenomenon can be attributed to population expansion, urban development, swift economic progress, and energy-demanding industries, all of which contribute to the exhaustion of fossil fuel reservoirs. Consequently, there arises a need for alternative, environmentally benign energy sources.

Renewable energies stand as the foremost viable alternatives, offering us a source of energy that is both clean and sustainable. This facet contributes significantly to safeguarding the environment and curtailing the release of greenhouse gases (Dogan & Seker, 2016). Consequently, several nations have embarked on substantial endeavours to integrate and advocate for the adoption of renewable energies, which have gained enhanced economic competitiveness (Pacesila et al., 2016). Numerous research investigations have demonstrated that as renewable energy consumption and per capita renewable electricity generation rise, carbon emissions decrease, while elevated consumption of non-renewable energy sources aligns with higher emissions levels (Jebli, et al., 2016).

Leveraging abundant sunlight and significant wind velocities, Hungary has set an ambitious agenda in the realm of clean energy (Munkácsy, 2020; Weidinger & Mendyl, 2022). The primary goal is to diminish the nation's reliance on external energy sources while aligning with the trajectory of establishing an environmentally conscious economy. Through the ongoing government energy efficiency programmes, Hungary will be able to meet the undertaken emission levels of the UN Framework Convention of Climate Change (Molnar et al., 2002; National energy strategy 2030, 2012).

The wind's behaviour at a specific site typically exhibits variations in both direction and speed, with the potential for rapid changes during gusty conditions. Foreseeing wind speed and direction holds paramount importance for the effective operation of wind farms. Diverse approaches and methodologies can be employed to fulfil this objective. In the pursuit of comprehending wind attributes and its energy potential, numerous statistical and spectral analysis techniques founded on the Weibull distribution have been proposed (Dabbaghiyan et al, 2016; Hadnagy & Tar, 2019; Hadnagy et al., 2020; Garbai & Kovacs, 2022). Investigating wind resources and assessing economic viability in four Iranian cities is documented in Fazelpour et al. (2017), aimed at mitigating investment risks. Here, wind power and energy density are evaluated through utilization of the Weibull distribution function. In a similar vein, Allouhi et al. (2017) explores the statistical scrutiny of wind data across six coastal locations in Morocco, employing hourly wind speeds and directions spanning five years. The findings underscore the precision of the Weibull distribution in effectively representing wind data frequencies.

To assess the wind potential we conducted a statistical analysis of the wind data, encompassing both speed and direction, collected from a mast positioned at a height of 65 m. The wind velocity was subsequently characterized using the Weibull distribution. The outcomes derived from this analysis prompted us to present an intricate examination of the wind data. This included evaluating daily and monthly wind speeds, as well as constructing diagrams showcasing the distribution of wind direction across seasons and the entire year. These analyses were complemented by an assessment of the energy density available within the studied area.

Site Description and Wind Data

The site known as Mosonmagyaróvar (Wieselburg-Ungarisch Altenburg, in German), marked by the UTM coordinate system XP70, presents a strategic location for potential exploration. Positioned at geographical coordinates of 47.867 latitude and 17.283 longitude in decimal degrees (WGS84), this site resides within the scenic landscapes of Hungary. In terms of degrees minutes seconds (WGS84), its latitude is 47 degrees 52 minutes 00 seconds, and its longitude is 17 degrees 17 minutes 00 seconds [1 – taogeo].

This geographical vantage point possesses a potential worth exploring, particularly in the context of wind energy generation. The convergence of natural forces, as denoted by the geographical coordinates, suggests an intriguing interplay of wind flows that could be harnessed for sustainable energy production (Szépszó et al., 2006; Weidinger et al., 2008; Tóth et al., 2017) (*Fig. 1*).

The wind speed and direction measurements were made at a height of 65 m on the top of the wind generator (*Fig. 1*). A Data Logger plays a pivotal role by recording the data obtained from the various sensors, effectively compiling a comprehensive dataset. The recorded data are thoughtfully organized into a file by the Data Logger with 10-minute averaged time together with wind energy production (Weidinger et al., 2008).



Figure 1: Satellite view of Mosonmagyaróvár [1 – taogeo] (left) and the E40 Enercon wind turbine (right).

Methodology

Temporal changes in the annual wind speed can be effectively understood by examining its probability distribution (Radics & Bartholy, 2002; Bartholy & Radics, 2008). Various mathematical functions are employed to depict the frequency curve of wind speed. Among these, the scientific community widely acknowledges the utility of the Weibull distribution. This distribution model is particularly favoured for time spans extending from a few weeks to an entire year, as it frequently provides a satisfactory representation of wind speed distribution (Redouane et al., 2012). The Weibull distribution is expressed in the following manner (Sadullayev et al., 2019):

$$f(v) = \frac{k}{c} \left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{k}{v}\right)^k\right]$$
(1)

The Weibull probability density function, denoted as f(v), pertains to wind speed (measured in m/s). Here, k represents the Weibull shape parameter, and signifies the scale parameter, c. The determination of the Weibull parameters can be accomplished by utilizing the moment method, leveraging the average wind speed and the standard deviation derived from wind data (Justus et al., 1978). Alternatively, a more straightforward method suggests acceptable approximations as provided (Sadullayev et al., 2019):

$$k = \left(\frac{\sigma_v}{\bar{v}}\right)^{-1.086} \quad (1 \le k \le 10) \tag{2}$$

$$c = \frac{\bar{\nu}}{\Gamma(1 + \frac{1}{k})} \tag{3}$$

The gamma function, denoted as Γ , is integral to the equation. The average wind speed \bar{v} and the standard deviation σ_v can be calculated as follows:

$$\bar{\nu} = \frac{1}{n} \left(\sum_{i=1}^{n} \nu_i \right) \tag{4}$$

$$\sigma_{\nu} = \left[\frac{1}{n-1}\sum_{i=1}^{n} (\nu_{i} - \bar{\nu})^{2}\right]^{0.5}$$
(5)

where n is the number of time steps in the period considered.

Variation of wind speed with height

Air friction against the surface of the ground induces a gradual deceleration of wind. How wind speed changes concerning height is contingent upon both ground roughness and shape. The relationship between wind speed (v) and height above the ground (h) can be expressed using the power law (Ohunakin & Akinnawonu, 2012; Jung & Schindler, 2021; Weidinger & Mendyl, 2022):

$$\frac{V}{V_0} = \left(\frac{h}{h_0}\right)^{\alpha} \tag{6}$$

In the equation, v_0 represents the velocity at a specified reference height, h_0 above the ground, while α corresponds to the power law exponent. This exponent, which is reliant on the surface roughness, typically falls within the range of 0.1 to 0.4.

Results and discussion

The variability of annual velocity over time can be effectively characterized through the lens of probability distribution. This distribution pattern offers significant insights into the wind resource of a particular location, making it a cornerstone in the field of wind energy analysis. Among the widely recognized distribution models, the Weibull distribution stands out as one of the most prominent choices (Morala-Argüello et al., 2012).

A visual representation of the Weibull distribution curve produced by the python programming language at a height of 65 m, is illustrated in *Fig. 2*. However, when considering the distinctive wind patterns prevalent in this specific region, it becomes evident that the Weibull distribution fails to satisfactorily approximate the observed experimental probability distribution, particularly in low to medium wind speeds. This deficiency highlights that the applicability of this distribution model is suboptimal for the unique wind characteristics of this region.



Figure 2: Weibull distribution curve at a height of 65 m (an illustration).

Table 1 provides yearly values for the mean wind speed (\bar{v}) , standard deviation (σ_v) and for two crucial Weibull parameters, namely, the scale parameter (c) and the shape parameter (k) values measured at a height of 65 m. These parameters are essential in characterizing the wind speed distribution and its probabilistic behaviour.

Looking at the variations in the scale parameter (c) across the years, it is noticeable that the values vary, ranging from approximately 0.808 to 0.935 (*Table 1*). This indicates that the

scale of wind speed fluctuates annually, possibly due to changing environmental conditions, topography, or other regional factors. Moving to the shape parameter (k), we observe a range from around 1.654 to 1.837. This parameter reflects the shape of the wind speed distribution. Lower values of k tend to indicate a broader distribution, while higher k values point to a more peaked distribution. The range observed in the shape parameter values suggests some variability in the distribution's shape across the years.

The variations in both the scale and shape parameters of the Weibull distribution across the years signify the dynamic nature of the wind speed behaviour at the specified height of 65 m. These annual changes could be influenced by a combination of local and seasonal factors that impact wind patterns, highlighting the importance of understanding these parameters for effective wind energy utilization and resource assessment.

Year	Mean (\bar{v})	Standard Deviation (σ_v)	Scale Parameter (<i>c</i>)	Shape Parameter (k)
2010	5.25	2.58	0.898	1.689
2011	4.96	2.43	0.935	1.654
2012	5.28	2.49	0.809	1.837
2013	5.16	2.53	0.864	1.711
2014	4.99	2.39	0.929	1.719

Table 1: Annual mean and standard deviation values and Weibull Parametersat 65 m height in Mosonmagyaróvár from 2010 to 2014.

The average wind speed for each year ranges from around 4.96 m/s in 2011 to 5.28 m/s in 2012. These variations suggest some year-to-year fluctuations in the overall wind speed at this location. The standard deviation of wind speed, which reflects the variability around the mean, shows similar trends. The values range from approximately 2.39 m/s in 2014 to 2.59 m/s in 2015. The maximum difference is 6,5% and 8.4%, respectively. This indicates that the dispersion of wind speeds around the mean also experiences some yearly changes.

In conclusion, the yearly fluctuations in both mean wind speed and standard deviation highlight the dynamic nature of wind patterns at this specific location. These variations could be attributed to a multitude of factors, including changes in local climate conditions, geographical features, or other external influences. Analyzing these statistical trends can contribute to a more comprehensive understanding of the wind resource potential and its variability over time.

Wind Direction

To gain a comprehensive understanding of wind direction distribution, the construction of a wind rose is an invaluable tool, utilizing the meteorological data collected at the study site. The wind rose visually represents the varying wind speeds originating from different directions. Its significance lies in its role in identifying optimal locations for wind turbine installation (Allouhi et al., 2017). When a substantial portion of wind energy originates from a specific direction, it becomes imperative to minimize obstacles and disturbances in that particular direction.

The wind rose, showcased in *Fig. 3*, depicts wind patterns originating from the study area at a height of 65 m. This visual representation offers insights into the prevailing wind directions and their respective speeds. This information is instrumental in planning the optimal placement of wind turbines, ensuring that they harness the maximum energy potential while minimizing any hindrances caused by obstacles or rough terrain.



Figure 3: Yearly wind rose at 65 m in Mosonmagyaróvár from 2010 to 2015 (30% of 10-minute averaged wind speed is greater than 6 m/s).

The wind rose indicating the most dominant wind direction in the northwest further enhances our understanding of the wind conditions at the studied site. 30% of the 10-minute averaged wind speed is greater than 6 m/s. It is good news for the applicability of the new generation wind generators in the 100-150 m rotor height. See the manuals of new generation wind turbines:

- Enercon (E-82 E2, [2 enercon]),
- Vestas (V110-2.0 MWIEC IIIA, [3 vestas]).

Fig. 4 shows the average wind speed by month from 2010 to 2015. Analyzing wind speed data is important for understanding the dynamics and potential of wind energy generation. Annual wind speed range varies from 4.96 m/s (low) to 5.28 m/s (*Table 1*). This variability is expected and reflects the natural fluctuations in wind patterns.

While it is challenging to assess long-term trends from a snippet of data, one might aggregate the data on a larger time scale (e.g., monthly or yearly averages) to identify potential seasonal or annual patterns. This can provide insights into wind speed trends that might influence energy production.



Figure 4: Average wind speed by month at 65 m height from 2010 to 2015.

The observations regarding the highest and the lowest wind speeds based on yearly and monthly averages provide valuable insights into the variability of wind conditions at the studied site:

Yearly Average Wind Speed:

- The highest yearly average wind speed being recorded in 2012 suggests that this particular year experienced overall stronger wind conditions compared to other years. This might be due to meteorological factors, regional weather patterns, or climatic influences that favoured higher wind speeds during that period.
- Conversely, the lowest yearly average wind speed in 2011 indicates that wind conditions during that year were relatively calmer or less favourable for wind energy generation.

Monthly Average Wind Speed:

- March Highest Monthly Average Wind Speed: The highest monthly average wind speed occurring in March highlights that this month experiences more robust wind conditions compared to other months. Seasonal shifts, temperature changes, and pressure gradients might contribute to elevated wind speeds during March. The mean wind speed is 5.76 m/s, and the standard deviation is approximately 2.7 m/s based on 10-minute time resolution wind measurements. There is notable variability in the data, with some days exhibiting values significantly different from this average.
- August Lowest Monthly Average Wind Speed: Conversely, the lowest monthly average wind speed observed in August suggests that this month tends to have less favourable wind conditions for energy generation. For August (Month 8), the mean is 4.47 m/s, and the standard deviation is approximately 2.1 m/s, indicating that there is relatively less variability in the data compared to some other months.

The variations in yearly average wind speeds might be attributed to long-term climatic cycles, which can impact wind patterns over the years. It is important to consider these trends when planning for wind energy projects. The fluctuations in monthly average wind speeds reflect the seasonal nature of wind patterns.

Conclusions

The observations regarding the highest and the lowest wind speeds based on yearly and monthly averages and incorporating the wind rose information provide valuable insights into the variability of wind conditions at the studied site.

Planning Considerations: These observations have implications for wind energy project planning and management. Developers can consider the observed variations when selecting turbine models, designing layouts, and forecasting energy production.

Climate Influence: The differences in wind speeds between years and months might be influenced by larger scale climate patterns, e.g., macrocirculation patterns, the number of the cyclonic and anticyclonic systems, and/or local factors such as geographical features, temperature gradients, and mesoscale convective systems.

Energy Generation Potential: The prevailing wind direction in the northwest suggests that a substantial portion of the wind energy resource originates from this direction. This information is pivotal for turbine placement to harness the maximum energy potential.

Turbine Alignment: Wind turbines are typically positioned to face the dominant wind direction to capture the highest energy yield. The northwest direction aligns with this approach, indicating a favourable setup for energy production.

Optimal Turbine Layout: Wind farm layouts can be optimized based on the dominant wind direction. Placing turbines in such a way that they are aligned with the prevailing wind minimizes turbulence and maximizes energy extraction.

In conclusion, the insights from wind speed analysis and yearly/monthly variations provide a comprehensive understanding of the wind resource at the site. This holistic perspective can guide decisions related to turbine placement, energy production projections, and the overall success of wind energy projects.

References

Allouhi, A., Zamzoum, O., Islam, M.R., Saidur, R., Kousksou, T., Jamil, A., Derouich, A., 2017: Evaluation of wind energy potential in Morocco's coastal regions. *Renew. Sust. Energ. Rev.*, 72: 311–324. <u>https://doi.org/10.1016/j.rser.2017.01.047</u>

- Bartholy, J., Radics, K., 2008: Estimating and modelling the wind resource of Hungary. Renew. Sust. Energ. Rev., 12 (3): 874–882. <u>https://doi.org/10.1016/j.rser.2006.10.009</u>
- Dabbaghiyan, A., Fazelpour, F., Abnavi, M.D., Rosen, M.A., 2016: Evaluation of wind energy potential in province of Bushehr, Iran. *Renew. Sust. Energ. Rev.*, 55: 455–466. https://doi.org/10.1016/j.rser.2015.10.148
- Dogan, E., Seker, F., 2016: The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries. *Renew. Sust. Energ. Rev.*, 60 (C): 1074–1085. https://doi.org/10.1016/j.rser.2016.02.006
- Fazelpour, F., Markarian, E., Soltani, N., 2017: Wind energy potential and economic assessment of four locations in Sistan and Balouchestan province in Iran. *Renew. Energy*, 109 (C): 646–667. https://doi.org/10.1016/j.renene.2017.03.072
- *Garbai, L., Kovacs, Z.*, 2022: The estimation and forecast of solar energy yield with Weibull distribution. *Int. Rev. Appl. Sci. Eng.*, 13(3): 247–256. https://doi.10.1556/1848.2021.00344
- Hadnagy, I., Tar, K., 2019: Approximation of wind speed distributions with theoretical distributions of meteorological stations located in different orographic conditions. *Idojaras*, 123(3): 329–349. <u>https://doi.org/10.28974/idojaras.2019.3.5</u>
- Hadnagy, I., Tar, K., Lázár, I., Kohut, E., 2020: Climatic conditions of wind energy use in the Polonyna Borzhava Mountains (Transcarpathia, Ukraine). DRC Sustainable Future: J. Food Agric. Environ., 1(2): 136–146. <u>https://doi.10.37281/DRCSF/1.2.6</u>
- IEA Statistics, 2020: CO₂ Emissions from Fuel Combustion, 2018. Int. Energy Agency. <u>https://www.iea.org/data-and-statistics/charts/fuel-share-of-co2-emissions-from-fuelcombustion-2018</u> (Last updates: 28. 08. 2023)
- *Jebli, M.B., Youssef, S.B., Ozturk, I.*, 2016: Testing environmental Kuznets curve hypothesis: the role of renewable and non-renewable energy consumption and trade in OECD countries. *Ecol. Indicat.*, 60: 824–831. https://doi.org/10.1016/j.ecolind.2015.08.031
- Jung, C., Schindler, D., 2021: The role of the power law exponent in wind energy assessment: A global analysis. Int. J. Energy Res., 45(6): 8484–8496. https://doi.org/10.1002/er.6382
- Justus, C.G., Hargraves, W.R., Mikhail, A., Graber, D., 1978: Methods for estimating wind speed frequency distributions. J. Appl. Meteorol., 17(3): 350–353. https://doi.org/10.1175/1520-0450(1978)017<0350:MFEWSF>2.0.CO;2
- Molnar, S., Molnar, M., Takacs, T., 2002: Comprehensive analysis of greenhouse gas emissions in Hungary. Int. J. Sustain. Dev., 5(1–2): 195–203. https://doi.org/10.1504/IJSD.2002.002566
- Morala-Argüello, P., Barreiro, J., Alegre, E., 2012: A evaluation of surface roughness classes by computer vision using wavelet transform in the frequency domain. Int. J. Adv. Manuf. Technol., 59: 213–220. https://doi.org/10.1007/s00170-011-3480-6
- Munkácsy, B. (ed.), 2020: Wind power at 21. century and Hungary. Energy Club, Policy Institute and methodology centre (Szélenergia a 21. században – és Magyarországon). Energiaklub Szakpolitikai Intézet és Módszertani Központ, Budapest, 2020 (In Hung.). <u>https://energiaklub.hu/files/study/Energiaklub_Sz%C3%A9lenergia%20a%2021.%20sz</u> <u>%C3%A1zadban_2.pdf</u>
- National energy strategy 2030, Ministry of National Development, 2012, 132p. <u>https://2010-2014.kormany.hu/download/7/d7/70000/Hungarian%20Energy%20Strategy%202030.pdf</u>
- Ohunakin, O.S., Akinnawonu, O.O., 2012: Assessment of wind energy potential and the economics of wind power generation in Jos, Plateau State, Nigeria. *Energy Sustain. Dev.*, 16: 78–83. <u>https://doi.org/10.1155/2015/581679</u>

- Pacesila, M., Burcea, S.G., Colesca, S.E., 2016: Analysis of renewable energies in European Union. Renew. Sust. Energ. Rev., 56(C): 156–170. <u>https://doi.10.1016/j.rser.2015.10.152</u>
- *Radics, K., Bartholy, J.*, 2002: Selected wind characteristics and potential use of wind energy in Hungary. Part II. *Időjárás*, 106(1): 59–74.
- Redouane, A., Taoukil, D., El Bouardi, A., Ajzoul, T., Ezbakhe, H., 2012: Comparative study of Weibull parameters for wind speed data of northern Morocco, Int. J. Eng. Innov. Technol., 2(5): 292–295.
- Sadullayev, N.N., Safarov, A.B., Nematov, Sh.N., Mamedov, R.A., 2019: Statistical analysis of wind energy potential in Uzbekistan's Bukhara region using Weibull distribution. Appl. Sol. Energy, 55(2): 126–132. <u>https://doi.org/10.3103/S0003701X19020105</u>
- Sheffield, J., 1999: World population and energy demand growth: the potential role of fusion energy in an efficient world. *Philos. Trans. R. Soc. A*, 357: 377–395. https://doi.org/10.1098/rsta.1999.0333
- Szépszó, G., Horányi, A., Kertész, S., Lábó, E., 2006: Wind climatology in Hungary by dynamical scaling of global fields. (Magyarországi szélklimatológia előállítása globális mezők dinamikai leskálázásával.) Results of wind and solar research in Hungary, Hungarian Meteorological Service. (Magyarországi szél és napenergia kutatás eredményei. Orsszágos Meteorológiai Szolgálat. (In Hung.) http://owww.met.hu/pages/palyazatok/winsolen/szel kezirat webre.pdf
- *Tóth, H., Brajnovits, B., Renczes, B.*, 2017: Statistical correction of the wind energy forecast at the Hungarian Meteorological Service. *Időjárás*, 121(2): 137–160.
- Weidinger, T., Gyöngyösi, A.Z., Kiss, A. Banfalvi, K., 2008: Uncertainties of wind power forecasts for Western Transdanubium from mesoscale NCEP/ETA and WRF models. Geophysical Research Abstracts, 10: EGU2008-A-07445. https://meetings.copernicus.org/www.cosis.net/abstracts/EGU2008/07445/EGU2008-A07445.pd
- Weidinger, T., Mendyl, A., 2022: The radiation and wind climate of Hungary, the meteorological background of wind and solar energy use (Magyarország sugárzási és szélklímája, a szél- és napenergia felhasználás meteorológiai háttere) "… születtem, elvegyültem és kiváltam." Tanulmánykötet Dr. Makra László Professzor 70. születésnapjára, Nagykőrös, 578-612, 2022 (In Hung.). ISBN 978-615-01-4018-6

Online references

- [1-taogeo] https://www.tageo.com/index-e-hu-v-09-d-m1280436.html
- [2 enercon] https://www.enercon.de/en/products/ep-2/e-82/
- $[3-vestas] \ \underline{https://us.vestas.com/en-us/products/2-mw-platform/V110-2-0-mw} \\ [3-vestas] \ \underline{https://us.vestas.com/en-us/products/2-mw-platform/V110-2-0-mw} \\ [3-vestas.com/en-us/products/2-mw-platform/V110-2-0-mw] \\ [3-vestas.com/en-us/products/2-mw-platform/V110-2-0-mw] \\ [3-vestas.com/en-us/products/2-mw-platform/V110-2-0-mw] \\ [3-vestas.com/en-us/products/2-mw-platform/V110-2-0-mw] \\ [3-vestas.com/en-us/products/2-mw-platform/V110-2-0-mw] \\ [3-vestas.com/en-us/products/2-mw-platform/V110-2-mw-platform/V10-2-mw-platform/V10-2-mw-platform/V10-2-mw-platform/V10-2-mw-platform/V10-2-mw-platform/V10-2-mw-platform/V10-2-mw-platform/V10-2-mw-platform/V10-2-mw-$

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