



Performance Analysis of Small-Scale Vertical Axis Wind Turbines Using Suitable Wind Speed Distribution at Bitlis Eren University Campus

Faruk ORAL¹ İsmail EKMEKÇİ² and Yunus SAYAN¹

How to cite: Orak, F., Ekmekçi, İ., & Sayan, Y., (2025). Performance analysis of small-scale vertical axis wind turbines using suitable wind speed distribution at Bitlis Eren University campus. *Sinop Üniversitesi Fen Bilimleri Dergisi*, 10(2), 340-353. <https://doi.org/10.33484/sinopfbd.1629946>

Research Article

Corresponding Author
Yunus SAYAN
ysayan@beu.edu.tr

ORCID of the Authors
F.O: 0000-0002-4114-0785
İ.E: 0000-0002-2247-2549
Y.S: 0000-0002-0871-6842

Received: 30.01.2025
Accepted: 18.07.2025

Abstract

This research examines the efficiency of small-scale vertical axis wind turbines for energy generation on the Bitlis Eren University campus. Wind data analysis was conducted using Weibull and Rayleigh distributions, with the most suitable distribution identified through error analysis. Three vertical axis wind turbine models from the same manufacturer, with rated capacities of 600W, 1000W, and 3000W, were assessed for energy production potential. Error analysis results indicated that the Weibull distribution provided the best fit for the wind data. Based on this distribution, the annual mean wind speed was found to be 3.17 m/s, while the average power density reached 45.25 W/m². Analysis of the results indicated that, among the evaluated models, the 1 kW turbine exhibited the most favorable capacity factor, suggesting a more efficient performance relative to its rated capacity under the given wind conditions. In contrast, the 3 kW turbine yielded the highest total annual energy output, highlighting its potential for maximizing absolute energy generation despite having a lower efficiency ratio. These results suggest that small-scale VAWTs can be viable for rooftop installation in regions with similar wind characteristics, offering a supplementary energy source for institutional or residential use. The study provided insights that could inform local energy policy, particularly in promoting decentralized renewable energy systems and integrating wind energy solutions into urban infrastructure.

Keywords: Wind energy, weibull distribution, rayleigh distribution, wind turbine, vertical axis

Bitlis Eren Üniversitesi Kampüsünde Uygun Rüzgâr Hızı Dağılımı Kullanılarak Küçük Ölçekli Dikey Eksenli Rüzgâr Türbinlerinin Performans Analizi

¹ Bitlis Eren University, Faculty of Engineering-Architecture, Department of Mechanical Engineering, Bitlis, Türkiye

²İstanbul Ticaret University, Engineering Faculty, Department of Industrial Engineering, İstanbul, Türkiye

Öz

Bu çalışma, Bitlis Eren Üniversitesi yerleşkesinde enerji üretimi amacıyla küçük ölçekli dikey eksenli rüzgâr türbinlerinin verimliliğini incelemektedir. Rüzgâr verilerinin analizi, Weibull ve Rayleigh dağılımları kullanılarak gerçekleştirilmiş ve hata analizi yoluyla en uygun dağılım belirlenmiştir. Aynı üreticiye ait, sırasıyla 600 W, 1000 W ve 3000 W anma gücüne sahip üç farklı dikey eksenli rüzgâr türbini modeli, enerji üretim potansiyeli açısından değerlendirilmiştir. Hata analizi sonuçlarına göre, Weibull dağılımı rüzgâr verileri için en iyi uyumu sağlamıştır. Bu dağılıma dayanarak, yıllık ortalama rüzgâr hızı 3.17 m/s, ortalama güç yoğunluğu ise 45.25 W/m² olarak belirlenmiştir. Sonuçların analizi, değerlendirilen türbin modelleri arasında 1 kW'lık türbinin en uygun

This work is licensed under a
Creative Commons Attribution
4.0 International License

kapasite faktörüne sahip olduğunu ve bu durumun, mevcut rüzgâr koşullarında anma gücüne göre daha verimli bir performans sergilediğini ortaya koymaktadır. Buna karşılık, 3 kW'lık türbin, daha düşük bir verimlilik oranına rağmen en yüksek yıllık toplam enerji üretimini sağlamış ve böylece mutlak enerji üretimini maksimize etme potansiyelini öne çıkarmıştır. Bu sonuçlar, küçük ölçekli düşey eksenli rüzgâr türbinlerinin benzer rüzgâr karakteristiklerine sahip bölgelerde çatı üstü kurulumlar için uygulanabilir olduğunu ve kurumsal ya da konut tipi kullanımlar için tamamlayıcı bir enerji kaynağı sunabileceğini göstermektedir. Çalışma, yerel enerji politikalarının şekillendirilmesine katkı sağlayabilecek bulgular sunmakta; özellikle merkezi olmayan yenilenebilir enerji sistemlerinin teşviki ve rüzgâr enerjisi çözümlerinin kentsel altyapıya entegrasyonu konularında yol gösterici niteliktedir.

Anahtar Kelimeler: Rüzgâr enerjisi, Weibull dağılımı, Rayleigh dağılımı, rüzgâr türbini, dikey eksen

Introduction

Energy is essential for human survival and development but increasing demand and limited fossil fuel reserves have led to a global energy crisis [1, 2]. The widespread use of fossil fuels contributes to environmental problems such as climate change and ecological imbalance. As awareness of sustainability and environmental protection grows, renewable energy is becoming a key solution for meeting future energy needs [1, 3, 4]. Although renewable energy sources such as wind and solar energy supplement conventional energy and play a growing role in some developed countries, they are not yet dominant in the energy sector. In addition to electricity, they contribute significantly to heat production without emitting greenhouse gases. This environmental benefit is a key driver behind the rising investment in renewable energy [5]. Many countries are developing technologies to better utilize renewable energy sources like wind, solar, geothermal, and biomass. Wind energy, in particular, is clean, renewable, land-efficient, and environmentally friendly, making it a strong candidate to help meet global energy demands [6]. Wind turbines harness the kinetic energy of wind and transform it into electricity. In power generation, large-scale, three-bladed, horizontal-axis wind turbines are the most widely utilized. However, the integration of small-scale wind turbines in areas unsuitable for larger systems can enhance overall energy production efficiency [7, 8]. Small-scale wind turbines are becoming increasingly widespread in individual homes, small businesses, and rural areas without access to the electrical grid. Using these turbines on the roofs of buildings makes it possible to benefit from wind energy in urban areas. Placing turbines on the rooftops of tall buildings can result in higher wind speeds, enabling greater efficiency of the wind turbine [9, 10]. Small-scale wind turbines can be divided into two types according to the rotation axis of the rotor: the horizontal axis and the vertical axis. The rotor of vertical-axis wind turbines (VAWT) is oriented vertically. These turbines can offer greater advantages in terms of operation and safety in urban applications compared to horizontal-axis turbines (HAWT) [11]. Due to their versatility and ability to capture wind from all directions thanks to their vertical axes, VAWTs are recommended for use in areas with high turbulence and frequently changing wind directions compared to HAWTs [8, 12]. Additionally, because of advantages such as lower maintenance costs,

reduced installation expenses, quieter operation, easier rooftop mounting, and better integration with the environment compared to HAWTs, VAWTs are considered more suitable for urban applications [8, 9, 12]. However, Darrieus-type VAWTs also face significant limitations, most notably low aerodynamic efficiency at suboptimal operating conditions and poor self-starting capability, particularly at low tip speed ratios (TSRs) [13]. The poor self-starting behavior arises primarily from insufficient torque generation during initial rotation, often requiring external assistance to reach operational speeds. This challenge is especially critical in small-scale implementations, where system simplicity and energy independence are prioritized. Additionally, fluctuating aerodynamic forces during operation may induce unsteady loads, leading to fatigue-related concerns and structural reliability issues [14]. To overcome these drawbacks, several aerodynamic enhancement strategies have been proposed. Modifications to blade geometry, pitch angle, and turbine solidity have been shown to improve lift forces and torque generation, especially during the startup phase. Blade profiles such as J-shaped airfoils have demonstrated the ability to increase torque output at low TSRs by combining lift and drag effects, though they may compromise performance at higher speeds [15]. Among passive flow control approaches, adaptive flaps have emerged as a promising solution. These flaps respond to varying flow conditions, delay separation, and increase lift without requiring external energy input, thereby improving power output and rotor acceleration during startup [13]. Another notable direction has been the development of hybrid VAWTs that combine lift-based Darrieus rotors with drag-based Savonius components. These systems leverage the high starting torque of Savonius blades and the superior high-speed efficiency of Darrieus blades. However, hybrid designs may introduce increased structural complexity, vortex-induced losses, and higher production costs [16]. Recent computational and experimental studies have further highlighted the influence of key physical parameters—such as the number of blades and the turbine’s moment of inertia—on the self-starting behavior. Dynamic simulations have proven essential in accurately capturing transient startup behavior, helping to refine design parameters for improved performance in real-world conditions [17]. Continued research into such integrated aerodynamic solutions remains essential for advancing the practical viability of VAWTs in small-scale and urban energy systems. This research identifies the most suitable wind speed distribution for the Bitlis Rahva region by analyzing wind data using Weibull and Rayleigh distributions. Additionally, the energy generation potential of three small-scale vertical axis wind turbines with varying rated capacities was estimated. Wind measurements from the Bitlis meteorological station in the Rahva region served as the basis for this analysis. To assess the accuracy of the Weibull and Rayleigh distributions, three distinct error evaluation criteria were applied. The Bitlis Eren University campus was selected as the study area due to its location within the city center and its comparatively favorable wind potential relative to other regions. Additionally, given the limited availability of wind data for this area, the study provides an important reference for future researchers. These factors enable a realistic evaluation of small-scale wind energy systems’ performance and offer valuable insights into the utilization of renewable energy

resources in the region. Thus, the study contributes meaningfully to both urban wind energy applications and local energy policy development.

Material and Methods

The estimation of energy output from wind turbines relies on wind data recorded at the intended production site. In this study, wind measurements were sourced from the Bitlis meteorological station, situated at $38^{\circ} 28'$ N latitude and $42^{\circ} 9'$ E longitude, under the Turkish State Meteorological Service. For this purpose, wind data measured at ten-minute intervals at a height of 10 meters between 2011 and 2012 was used. In the study, the building with block number R6, located among the Bitlis Eren University staff residences in the Rahva campus at the Bitlis city center, was chosen as the application area. The R6 building was selected due to the prevailing wind direction in the region, which predominantly came from the southwest—a direction associated with the highest wind energy potential. Additionally, considering structural obstructions in that direction, the R6 building was the farthest from these barriers, offering a cleaner and less turbulent wind flow. These characteristics made R6 a technically suitable location for evaluating rooftop wind energy potential within the study area. The Bitlis meteorological station, where the wind data were obtained, is located within the Bitlis-Rahva region selected as the application area. The satellite image of the study area is given in Figure 1.



Figure 1. Satellite imagery of the project location [18]

Before estimating the energy yield from a wind turbine, evaluating the wind potential of the area is essential. This requires an initial statistical analysis of wind data. The mean wind speed (v_m), standard deviation (σ), and wind power density (P_m) were calculated using the following equations [19].

$$v_m = \frac{1}{n} \sum_{i=1}^n v_i \quad (1)$$

$$\sigma = \left[\frac{1}{n-1} \sum_{i=1}^n (v_i - v_m)^2 \right]^{1/2} \quad (2)$$

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

In these formulas, v_i refers to the recorded wind speed, ρ represents air density, and n denotes the total count of wind speed measurements. Selecting the most suitable wind speed distribution function was essential for accurately estimating the energy output of wind turbines. The Weibull and Rayleigh distributions were widely utilized in scientific research to model wind speed variations [20-24]. The probability density function of the Weibull distribution ($f(v)$), along with the equations for mean wind speed, standard deviation, and wind power density, are presented below [25-27].

$$f(v) = \frac{k}{c} \left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^k\right] \quad (4)$$

$$v_m = c \Gamma\left(1 + \frac{1}{k}\right) \quad (5)$$

$$\sigma = c \left[\Gamma\left(1 + \frac{1}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right) \right]^{1/2} \quad (6)$$

$$P_m = \frac{1}{2} \rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \quad (7)$$

In these formulas, k represents the shape parameter, c denotes the scale parameter, and Γ refers to the gamma function. When the shape parameter in the Weibull distribution is set to 2, it simplifies into the Rayleigh distribution. Since the Rayleigh distribution relies on a single parameter, it offers less flexibility than the Weibull distribution but is easier to compute. In this study, the maximum likelihood method was used to estimate the parameters of the Weibull and Rayleigh probability density functions. The obstacles arising from the topographic structure of the energy production site will affect the wind speed. An increase in height will increase wind speed as it reduces the effect caused by terrain roughness. To estimate the energy output of a wind turbine, wind speed values at the turbine's hub height had to be considered. In this study, it was assumed that the selected turbines would operate on the rooftop of the designated building. Consequently, determining wind speeds at the hub height became necessary. These

wind speeds were calculated using the power law equation provided below, which adjusts wind speeds from the measurement height to the required height [28].

$$\frac{v}{v_z} = \left(\frac{h}{h_z}\right)^\alpha \tag{8}$$

In this equation, v denotes the wind speed measured at height h , and v_z is the estimated wind speed at height h_z . The exponent α ranges from 0.05 to 0.5, influenced by the surface roughness of the measurement location and atmospheric stability conditions [20]. Determining the wind speed distribution function that best represents the wind data was crucial for accurately predicting the energy obtained from wind turbines. This study assessed the accuracy of Weibull and Rayleigh distributions using root mean square error (RMSE), chi-square (χ^2), and the coefficient of determination (R^2). The formulas for these evaluation metrics were provided below [26, 29].

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^n (y_i - x_i)^2 \right]^{0.5} \tag{9}$$

$$\chi^2 = \sum_{i=1}^n \frac{(y_i - x_i)^2}{n - m} \tag{10}$$

$$R^2 = \frac{\sum_{i=1}^n (y_i - z_i)^2 - \sum_{i=1}^n (x_i - y_i)^2}{\sum_{i=1}^n (y_i - z_i)^2} \tag{11}$$

Here, the observed wind speed frequency is denoted as y_i , while its average value is represented as z_i . The predicted frequency is given as x_i , with n indicating the total number of observations and m referring to the number of parameters in the distribution function. The power generated from the wind turbine P_T , can be estimated using the power production curve of the wind turbine. The power production curve of a wind turbine can be modeled by expressing the power value that can be obtained using a third-degree equation as follows [30, 31].

$$P_T(v) = \begin{cases} 0, & v < v_1 \\ (a_1 v^3 + a_2 v^2 + a_3 v + a_4) P_R, & v_1 \leq v \leq v_R \\ P_R, & v_R < v \leq v_0 \\ 0, & v > v_0 \end{cases} \tag{12}$$

In this case, a_1, a_2, a_3, a_4 are regression coefficients. The turbine starts generating electricity at v_1 (cut-in wind speed), reaches its nominal output at v_R (rated wind speed), and stops producing power at v_0 (cut-out wind speed). The parameter P_R represents the turbine's rated power capacity [30]. The potential energy output of a wind turbine was calculated using the equation provided below.

$$E_T = T \int_{v_1}^{v_0} P_T(v) f(v) dv \tag{13}$$

Here T stands for time.

The capacity factor (C_F) indicates the performance of a wind turbine in terms of energy generation. It was calculated as the proportion of actual energy output to the maximum possible energy at rated power. The formula for computing the capacity factor is provided below [30].

$$C_F = \frac{E_T}{TP_R} \quad (14)$$

In this study, the energy production value was estimated using three types of vertical axis wind turbines of Aeolos company with different rated powers (Figure 2).



Figure 2. Aeolos wind turbine with a vertical-axis design [32]

Table 1 presents the technical specifications of the selected wind turbines, while Figure 3 illustrates their power generation curves. The power curves of the turbines used in the study were obtained from the manufacturer. Energy production calculations were carried out based on these power curves, while also considering the elevation of the study area along with ambient temperature and pressure values. These meteorological parameters were obtained from the nearest official weather station, and the resulting air density was adjusted specifically for the study location. This approach helped ensure that energy production estimates better reflected real operating conditions.

Table 1. Specifications of the turbines [32-34]

Specifications with their unit	Manufacturer & Model		
	Aeolos-V 0.6kW	Aeolos-V 1kW	Aeolos-V 3kW
Rated power (P_R : W)	600	1000	3000
Maximum output power (W)	800	1500	3800
Rotor diameter (m)	1.6	2.0	2.8
Output voltage (Volt=V)	24	48/110	120/220
Hub height (m)	2.0	2.8	3.6
Start-up wind speed (m/s)	1.5	1.5	1.5
Cut in wind speed (v_I : m/s)	2.5	2.5	2.5
Rated wind speed (v_R : m/s)	10	10	11
Survival wind speed (m/s)	50	50	52.5
Swept area (m ²)	2.01	3.14	6.16
Number of blades	3	3	3
Turbine weight (kg)	18	28	106
Generator efficiency (%)	96	96	96
Noise level (dB(A))	< 45	< 45	< 45
Temperature range (°C)	-20 to +50	-20 to +50	-20 to +50
Design lifetime (Years)	20	20	20
Generator	Each generator equipped with three-phase permanent magnets		

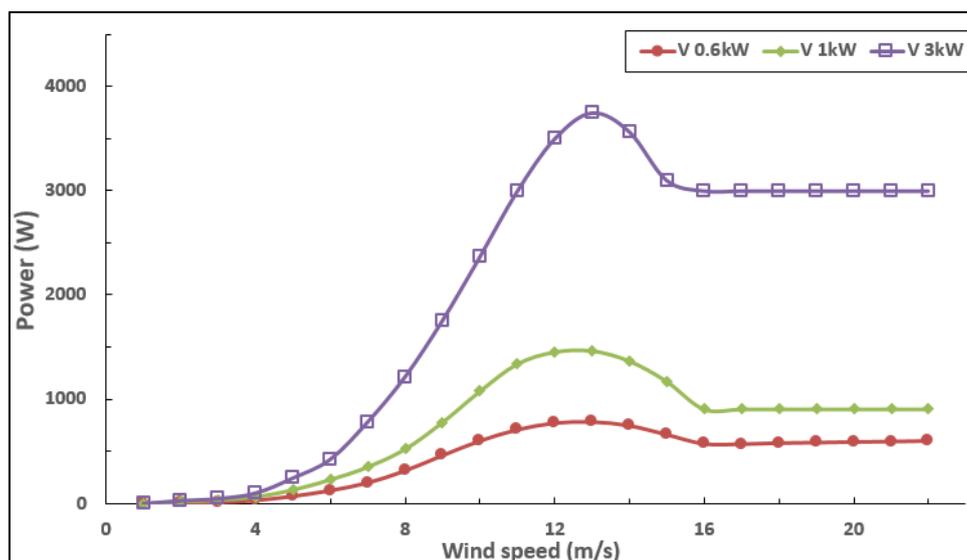


Figure 3. Power curves of wind turbines [32-34]

Results and Discussion

Figure 4 illustrates the probability density function for wind speeds based on Weibull, Rayleigh, and observed results. In addition, Table 2 provides the results obtained from Weibull and Rayleigh distributions alongside the observed data. According to observations, the yearly mean wind speed and power density are 3.16 m/s and 50.07 W/m², respectively. As per the Weibull model, the calculated annual average wind speed was 3.17 m/s, with a power density of 45.25 W/m². The shape parameter (k)

was 1.48, while the scale parameter (c) was 3.5 m/s. The Weibull model's results closely aligned with the observed data.

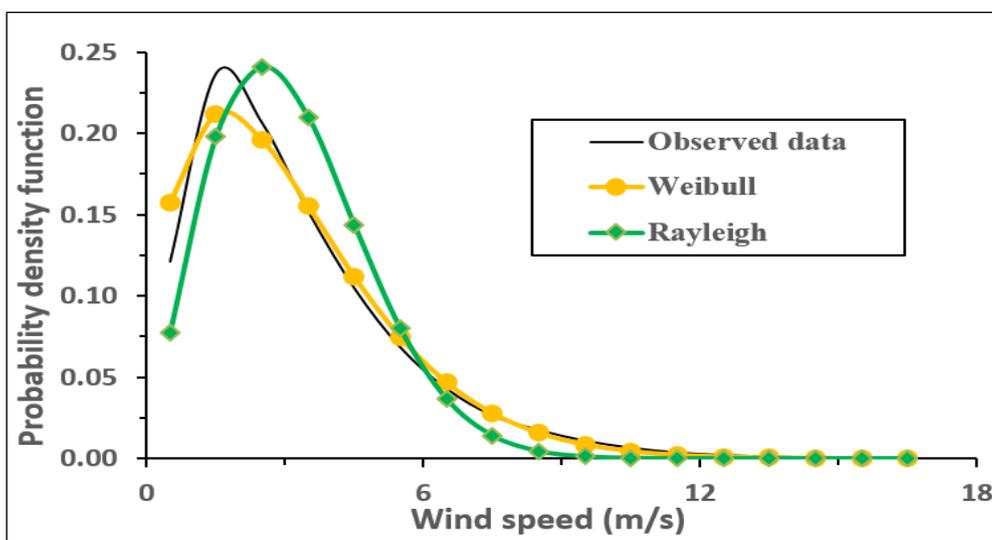


Figure 4. Frequency distribution

Table 2. Statistical results of wind data (for annual average)

	v_m (m/s)	k	c (m/s)	σ	P_m (W/m ²)
Observed	3.16	-	-	2.2448	50.07
Weibull distribution	3.17	1.48	3.50	2.1789	45.25
Rayleigh distribution	3.14	2	3.54	1.6386	30.21

Error analysis results were given in Table 3. The highest R^2 , lowest $RMSE$, and χ^2 values were found in the Weibull distribution. Findings indicate that the Weibull distribution offered the closest fit to the observed wind data.

Table 3. Error analysis results

	R^2	$RMSE$	χ^2
Weibull distribution	0.976944	0.011401	0.000130
Rayleigh distribution	0.893379	0.024517	0.000601

Figure 5 illustrates the sectoral frequency variation of wind speed. The highest frequency, reaching 27.5%, occurred in the South-Southwest direction. Thus, it was identified as the dominant wind direction in the region.

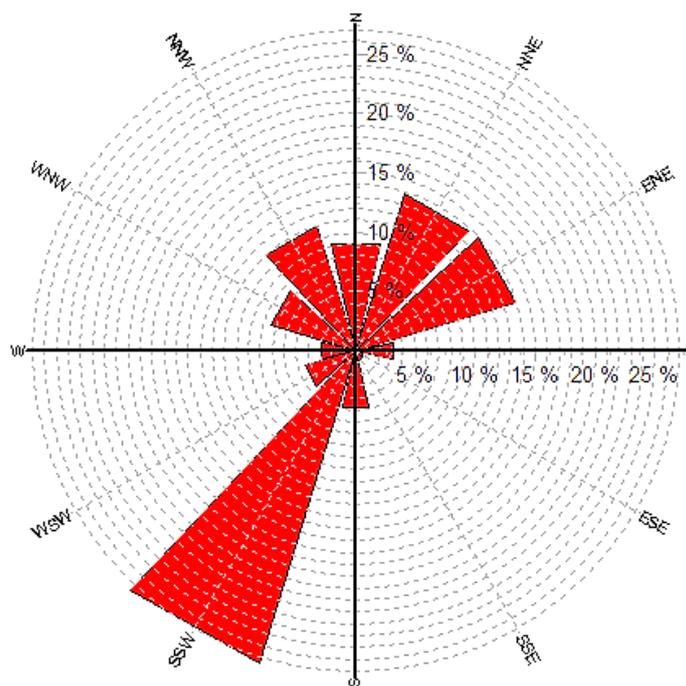


Figure 5. Sectoral frequency variation of wind speed

The wind speed distribution was analyzed at the designated turbine hub height. At this height, the annual mean wind speed was recorded as 4.13 m/s, while the average power density reached 87.44 W/m². Due to the high elevation of the study area, the air density was reduced, which led to a relatively low power density value. Table 4 presents the results of the wind power plant assessment for the turbines. The highest annual energy output, measured at 2849 kWh, was generated by a 3 kW-rated wind turbine. In the evaluation of turbines according to their capacity factors, the largest capacity factor was 17% for the turbine with a rated power of 1 kW. The highest rated nominal power operating hours were observed in the 0.3 and 1 kW turbines. One notable observation in the results was the apparent contradiction between the total annual energy output and the capacity factor of the 3-kW wind turbine. Although this turbine produced the highest total energy among the evaluated models, it had the lowest capacity factor. As detailed in Table 4, this outcome stemmed from the relatively short duration the 3-kW turbine operated at or near its rated power under the local wind conditions.

Table 4. Analysis results

	0.6 kW	1 kW	3 kW
Operational time (hours/year)	6462	6462	6462
Operational time at rated power (hours/year)	405	405	273
Capacity factor (%)	15.54	17.16	12.38
Power energy output (kWh/year)	714.983	1316.275	2848.546
Energy production per unit kW (kWh/kW)	1191.638	1316.275	949.515

Conclusions

This research examined the energy generation efficiency of small-scale vertical axis wind turbines. To model wind speed distribution, both Weibull and Rayleigh distributions were used. Following error analysis, the most suitable wind speed distribution was determined, and the energy output of the selected turbines was calculated. Error analysis results indicated that the Weibull method provided the most accurate wind speed distribution. Based on this distribution, the annual mean wind speed was determined to be 3.17 m/s, with k and c parameters calculated as 1.48 and 3.50 m/s, respectively. The average wind power density was 45.25 W/m². Additionally, the dominant wind direction was the South-Southwest (SSW), with a frequency of 27.5%. The highest energy production per unit kW was achieved by the 1 kW nominal power wind turbine, 1316 kWh. The largest capacity factor was obtained from the wind turbine with 1 kW nominal power. The annual energy production operation period of this turbine was determined to be approximately 6462 hours.

As a result:

- For the study region where the annual energy production periods of the turbines were high, it was recommended to use small-scale wind turbines for energy production purposes in individual residences or small businesses.
- In selecting small-scale vertical axis wind turbines for the region, it was considered more efficient to select turbines with low rated wind speed characteristics that could start energy production at low speeds.

Acknowledgements Part of this study was presented as a paper at the following conference: 12th Global Conference on Global Warming (GCGW-2024) May 16-19, 2024, Şanlıurfa, Türkiye

Funding/Financial Disclosure The authors have not received any financial support for the research, authorship, or publication of this study.

Ethics Committee Approval and Permissions The work does not require ethics committee approval and any private permission.

Conflict of Interests The authors stated that there are no conflict of interest in this article.

Authors Contribution Authors contributed equally to the study. All authors read and approved the final manuscript.

References

- [1] Shi, H., Dong, Z., Xiao, N., & Huang, Q. (2021). Wind speed distributions used in wind energy assessment: a review. *Frontiers in Energy Research*, 9, 769920.
- [2] Türkdoğan, S., Dilber, S., & Çam, B. (2018). Hibrit enerji sistemlerinin şebekeden bağımsız bir çiftlik evinde uygulanabilirliğinin ekonomik ve teknik açıdan incelenmesi. *Sinop Üniversitesi Fen Bilimleri Dergisi*, 3(2), 52-65.

- [3] Li, J., Wang, G., Li, Z., Yang, S., Chong, W. T., & Xiang, X. (2020). A review on development of offshore wind energy conversion system. *International Journal of Energy Research*, 44(12), 9283-9297.
- [4] Veers, P., Dykes, K., Lantz, E., Barth, S., Bottasso, C. L., Carlson, O., Clifton, A., Green, J., Green, P., Holttinen, H., Laird, D., Lehtomäki, V., Lundquist, J. K., Manwell, J., Marquis, M., Meneveau, C., Moriarty, P., Munduate, X., Muskulus, M., Naughton, J., Pao, L., Paquette, J., Peinke, J., Robertson, A., Sanz Rodrigo, J., Sempreviva, A. M., Smith, J. C., Tuohy, A., & Wisser, R. (2019). Grand challenges in the science of wind energy. *Science*, 366(6464), eaau2027. <https://doi.org/10.1126/science.aau202>
- [5] Maradin, D. (2021). Advantages and disadvantages of renewable energy sources utilization. *International Journal of Energy Economics and Policy*, 11(3), 176-183.
- [6] Kumar, Y., Ringenberg, J., Depuru, S. S., Devabhaktuni, V. K., Lee, J. W., Nikolaidis, E., Andersen, B., & Afjeh, A. (2016). Wind energy: Trends and enabling technologies. *Renewable and Sustainable Energy Reviews*, 53, 209-224. <https://doi.org/10.1016/j.rser.2015.07.200>
- [7] Oral, F. (2023). Use of small-scale wind turbines in road lighting. *Light & Engineering*, 31(3), 109-117. <https://doi.org/10.33383/2022-118>
- [8] Tummala, A., Velamati, R. K., Sinha, D. K., Indraja, V., & Krishna, V. H. (2016). A review on small scale wind turbines. *Renewable and Sustainable Energy Reviews*, 56, 1351-1371. <https://doi.org/10.1016/j.rser.2015.12.027>
- [9] Çetin, S. K., Genç, M. S., & Daldaban, F. (2019). Dikey eksenli rüzgâr türbinleri-küçük ölçekli uygulamalar. *Bilecik Şeyh Edebali Üniversitesi Fen Bilimleri Dergisi*, 6(2), 539-551. <https://doi.org/10.35193/bseufbd.643828>
- [10] Oral, F. & Ekmekçi İ. (2024, 16 - 19 May). *Estimation of Energy Generation in A Vertical Axis Small-Scale Wind Turbine Using Wind Speed Distribution*. 12th Global Conference on Global Warming (GCGW-2024), Şanlıurfa, Turkey. <file:///C:/Users/PC/Downloads/ie%20fo%20GCGW-2024-Proceedings%20Book.pdf>.
- [11] Yen, J., & Ahmed, N. (2012). Improving safety and performance of small-scale vertical axis wind turbines. *Procedia Engineering*, 49, 99-106. <https://doi.org/10.1016/j.proeng.2012.10.117>
- [12] Kouloumpis, V., Sobolewski, R. A., & Yan, X. (2020). Performance and life cycle assessment of a small-scale vertical axis wind turbine. *Journal of Cleaner Production*, 247, 119520. <https://doi.org/10.1016/j.jclepro.2019.119520>
- [13] Tanürün, H. E. (2024). Improvement of vertical axis wind turbine performance by using the optimized adaptive flap by the Taguchi method. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 46(1), 71-90. <https://doi.org/10.1080/15567036.2023.2279264>
- [14] Zamani, M., Maghrebi, M. J., & Varedi, S. R. (2016). Starting torque improvement using J-shaped straight-bladed Darrieus vertical axis wind turbine by means of numerical simulation. *Renewable Energy*, 95, 109-126.
- [15] Kaya, A. F., Tanürün, H. E., & Acır, A. (2022). Numerical investigation of radius dependent solidity effect on H-type vertical axis wind turbines. *Politeknik Dergisi*, 25(3), 1007-1019.
- [16] Celik, Y., Ingham, D., Ma, L., & Pourkashanian, M. (2023). Novel hybrid blade design and its impact on the overall and self-starting performance of a three-dimensional H-type Darrieus wind turbine. *Journal of Fluids and Structures*, 119, 103876.

- [17] Celik, Y., Ma, L., Ingham, D., & Pourkashanian, M. (2020). Aerodynamic investigation of the start-up process of H-type vertical axis wind turbines using CFD. *Journal of Wind Engineering and Industrial Aerodynamics*, 204, 104252.
- [18] Google Earth, <http://earth.google.com>. Accessed on January 17, 2025.
- [19] Oral, F. (2020). Statistical analysis of the wind energy potential of Bitlis province. *Dicle University Journal of Engineering*, 11(2), 671-678. <https://doi.org/10.24012/dumf.655780>
- [20] Oral, F. (2024). Comparative analysis of different methods in estimating wind speed distribution, and evaluation of large-scale wind turbine performance in Rahva-Bitlis, Turkey. *IET Renewable Power Generation*, 18(1), 95-108. <https://doi.org/10.1049/rpg2.12898>
- [21] Serban, A., Paraschiv, L. S., & Paraschiv, S. (2020). Assessment of wind energy potential based on Weibull and Rayleigh distribution models. *Energy Reports*, 6, 250-267. <https://doi.org/10.1016/j.egy.2020.08.048>
- [22] Balpetek, N., & Kavak Akpınar, E. (2019). Statistical analysis of wind speed distribution with Sinop-Turkey Application. *Journal of Thermal Engineering*, 5(4), 277-292.
- [23] Bidaoui, H., El Abbassi, I., El Bouardi, A., & Darcherif, A. (2019). Wind speed data analysis using Weibull and Rayleigh distribution functions, case study: five cities northern Morocco. *Procedia Manufacturing*, 32, 786-793. <https://doi.org/10.1016/j.promfg.2019.02.286>
- [24] Aslan, A. (2018). Balıkesir rüzgar enerjisi potansiyelinin araştırılması ve türbinlerin ekonomik analiz kapsamında karşılaştırılması. *Isı Bilimi ve Tekniği Dergisi*, 38(1), 25-41.
- [25] Guesmi, T., Farah, A., Marouani, I., Alshammari, B., & Abdallah, H. H. (2022). Chaotic sine-cosine algorithm for chance-constrained economic emission dispatch problem including wind energy. *IET Renewable Power Generation*, 14(10), 1808–1821. <https://doi.org/10.1049/iet-rpg.2019.1081>
- [26] Costa Rocha, P. A., de Sousa, R. C., de Andrade, C. F., & da Silva, M. E. V. (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>
- [27] Celik, A. N. (2003). 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>
- [28] Eskin, N., Artar, H., & Tolun, S. (2008). Wind energy potential of Gokceada Island in Turkey. *Renewable and Sustainable Energy Reviews*, 12(3), 839–851. <https://doi.org/10.1016/j.rser.2006.05.016>
- [29] Çakmakçı, B., & Hüner, E. (2022). Evaluation of wind energy potential: a case study. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 44(1), 834-852. <https://doi.org/10.1080/15567036.2020.1811810>
- [30] Oral, F., Ekmekçi, İ., & Onat, N. (2015). Weibull distribution for determination of wind analysis and energy production. *World Journal of Engineering*, 12(3): 215-220. <https://doi.org/10.1260/1708-5284.12.3.215>
- [31] Arslan, O. (2010). Technoeconomic analysis of electricity generation from wind energy in Kutahya, Turkey. *Energy*, 35(1), 120-131. <https://doi.org/10.1016/j.energy.2009.09.002>

- [32] Aeolos-V 1kW vertical wind turbine. January 17, 2025. <https://www.windturbinestar.com/1kwv-v-aeolos-wind-turbine.html>.
- [33] Aeolos-V 600W rooftop wind turbine. January 17, 2025. <https://www.windturbinestar.com/600wv-v-aeolos-wind-turbine.html>.
- [34] Aeolos-V 3kW vertical wind turbine. January 17, 2025. <https://www.windturbinestar.com/3kwv-v-aeolos-wind-turbine.html>.