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Analysis of Wind Potential as a Form of New and Renewable Energy at Manna in Bengkulu

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ABSTRACT

The energy from fossil fuels is declining due to modern society's high energy demands. This study investigates the potential of renewable energy, focusing on wind energy as a sustainable solution. It analyzes the Weibull and Rayleigh distributions to assess wind speed suitability in Bengkulu. The average wind speed at Manna Beach is 2.5 m/s, with a minimum of 0.01 m/s and a maximum of 10.01 m/s. Data validation tests were conducted at a height of 10 meters using Chi-Square and Kolmogorov-Smirnov methods. The chi-square test results indicated the values of 0.11 for Weibull and 0.42 for Rayleigh. The Kolmogorov-Smirnov test yielded value of 0.82 for Weibull and 0.84 for Rayleigh. Therefore, the suggesting Weibull was more suitable. Furthermore, using the Aventa AV-7 wind turbine, an annual output of 11,096.29 kWh can supply 30% of the electricity demand, which requiring 199 turbines. Ultimately, 40 turbines effectively contribute 6% or 440,621.94 kWh of total demand.

KEYWORDS: *Renewable energy, Wind energy, Weibull distribution, Rayleigh distribution, Wind turbine.*

NOMENCLATURE

$RMSE$	Root Mean Square
$f_{Weibull}$	PDF Weibull
$f_{Rayleigh}$	PDF Rayleigh
k	Shape Factor
$c_{Weibull}$	Scale Factor Weibull
$c_{Rayleigh}$	Scale Factor Rayleigh
X^2	Chi-Square
db	Degrees of Freedom
V	Wind Speed
V_m	Average Wind Speed
σ	Standard Deviation
y_i	Primary Wind Speed Data
x_i	Secondary Wind Speed Data
F_X	Theoretical Cumulative Distribution Function
S_n	Empirical Distribution Function
n	Number of Data

1.0 INTRODUCTION

Energy plays a crucial role that is essential for human activities, particularly in the economy, households, industry, business, and transportation. A significant proportion of the world's energy supply comes from fossil fuels, which are non-renewable resources [1]. The availability of energy is expected to increase in all countries, especially in Indonesia, depending on the availability of resources. According to the Ministry of Energy and Mineral Resources (ESDM), Indonesia's reserves will only last for 9.5 years. Therefore, Indonesia is currently aiming to increase the share of new and renewable energy to at least 23% by 2025 and 31% by 2050 [2,3].

In this regard, the government supports the use of new and renewable energy (NRE). The utilization of NRE contributes to reducing dependence on or decreasing the use of fossil fuels, which are becoming increasingly depleted for energy resource needs [4–6]. New and renewable energy has significant potential in Indonesia, particularly wind energy, which is defined as moving air and is one of the natural energy sources obtained through the conversion of kinetic energy into electrical energy [2,7,8]. Indonesia has an average wind speed of 3 to 6 m/s, with the greatest wind energy potential in maritime areas with wind speeds of over 4.16 m/s, such as in the Indian Ocean, on the south coast of the island of Java and Nusa Tenggara [5,9–11].

On the island of Sumatra, there are many areas with significant wind potential, including Aceh with an energy potential of 894 MW, North Sumatra with 356 MW, West Sumatra with 428 MW, Bengkulu with 1,513 MW, Enggano Island with 2,422 MWh and Lampung with 1,137 MW [12,13]. Given this substantial potential, it is essential to assess the wind energy potential in each region to determine how it can be utilized for electricity generation. However, the outcomes or

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benefits of this utilization heavily depend on the available energy potential [14,15].

2.0 RESEARCH METHOD

This research aims to evaluate the potential of wind energy in the waters of Bengkulu, located on the island of Sumatra, which possesses considerable promise as a renewable energy source. To assess the potential of wind energy as a source of electrical energy, several steps are necessary in the process of converting wind energy into electricity in the waters of Bengkulu. The steps involved are illustrated in the flowchart shown in Figure 1.

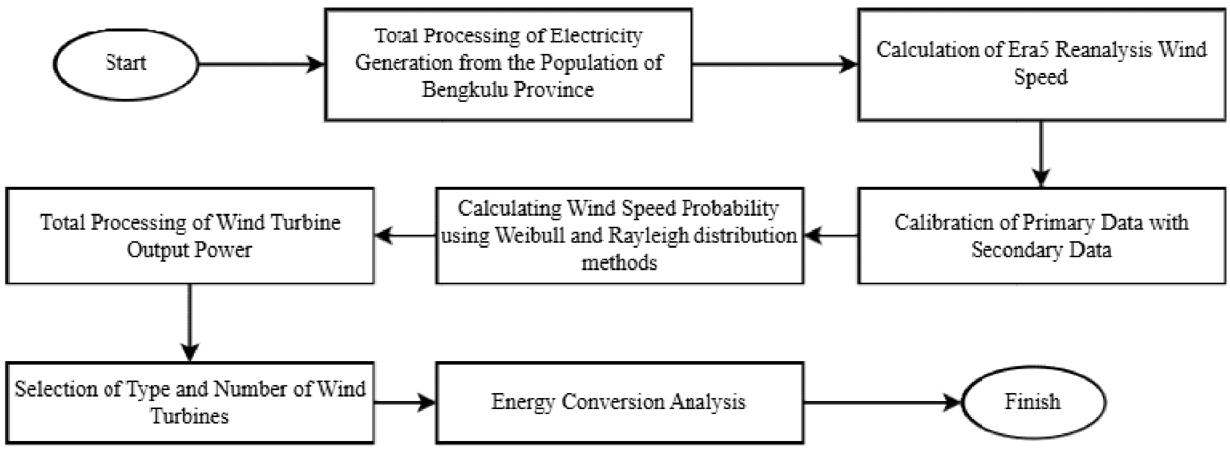

Figure 1: Research Flowchart

2.1 Resource and Equipment

This research employs a combination of primary and secondary data to evaluate wind speed in Bengkulu. It utilizes hardware equipment and data sourced from various websites, as detailed in Table 1.

Table 1: Equipment used in the study

No	Data	Time	Source
1	Primary Wind Speed	Aug-Sep 2024	Field Acquisition
2	Secondary Wind Speed	Jan 2004-Dec 2024	ERA-5 ECMWF
3	Type of Wind Turbine	-	Wind turbines database
4	Electric Energy	2023	Statistical PLN 2023
5	Housing and Public Building Facilities	2023	BPS Bengkulu

2.2 Research Preparation Process

In Figure 1, the workflow of this research is explained, consisting of three main parts: Input, Process, and Output. The Input section begins with problem identification, literature review, and data collection. The data collected includes wind speed data sourced from ERA-5 ECMWF forecasts and the field acquisition using Davis Pro 2 instrument. ERA5 is the fifth-generation atmospheric reanalysis by ECMWF, providing global climate data from January 1940 to the present. Field acquisition collects wind speed and direction data in Bengkulu. This data collection serves as the basis for calculations to make subsequent decisions.

To analyze the wind speed data in detail, comparisons are made, and the wind speed distribution is processed and generated. Following this, the power output from the wind turbine will be identified to select the appropriate turbine type based on the wind speed distribution [16]. The final analysis will determine the turbine requirements based on the power output that will meet the electricity demand. Ultimately, this will allow for the determination of the type and number of wind turbines needed [14].

2.3 Theoretical Distribution

Theoretical distribution is used as a decision-making tool in calculating the probability of each event. In selecting the appropriate distribution to predict the potential wind energy generated from wind speed, the distributions used in this study are the Weibull distribution and the Rayleigh distribution, which have accurate representations of wind speed at low levels. The probability density function is represented in equation (1) for the Weibull distribution and in equation (2) for the Rayleigh distribution. Each parameter required for the distributions is explained in equations (3) to (5) [16,17].

$$f_{weibull}(U) = \left(\frac{k}{c}\right)\left(\frac{Vm}{c}\right)^{k-1} exp\left[-\left(\frac{Vm}{c}\right)^{k}\right] \tag{1}$$

$$f_{rayleigh}(V) = \frac{2v}{c^2}\exp\left[-\left(\frac{V}{c}\right)^2\right] \tag{2}$$

$$k = \left(\frac{\sigma}{Vm}\right)^2 \tag{3}$$

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$$c_{weibull} = Vm \left(\frac{k^{2,6674}}{0,184 + 10,186k^{2,73859}} \right) \quad (4)$$

$$c_{rayleigh} = \frac{2V_m}{\sqrt{\pi}} \quad (5)$$

Each distribution requires parameters, where the shape parameter (k) represents the variability and stability of the wind, and the scale parameter (c) has the same dimensions as wind speed. To calculate the shape parameter, the standard deviation (σ) of the wind speed data is needed, while the scale parameter c requires the average wind speed (V_m) and the value of the shape parameter.

2.4 Wind Turbine Output Power

Annual wind speed probability is calculated based on wind categories using a distribution that aligns with the specifications of the relevant wind turbine, as indicated in equation (10). The annual output power of the wind turbine is determined using equation (11). Additionally, the energy demand is calculated by determining the number of wind turbines required, as described in equation (12).

$$f_{Annual} = f_{wind\ groups} \times 24\ hour \times 365\ day \quad (10)$$

$$Power_{total} = \sum_{i=1}^{n} Power_{group} \quad (11)$$

$$N_{turbine} = \frac{Power_{need}}{Power_{total}} \quad (12)$$

To determine the number of wind turbines needed, it is necessary to divide the total electricity demand $(Power_{need})$ by the annual output power of the wind turbines $(Power_{total})$.

2.5 Distribution Fitting

The methods employed in this research are Chi-Square and Kolmogorov-Smirnov[9]. The Chi-Square method is used for the probability density function of random variable data, while the Kolmogorov-Smirnov method is applied to the cumulative density function. The Chi-Square value is calculated using equation (6) to evaluate the results with equation (7), and these results will be compared against the Chi-Square distribution table. The Kolmogorov-Smirnov value is obtained using equation (8) [9].

$$X_{count}^2 = \sum_{i=1}^{m} \frac{(y_i - x_i)^2}{x_i} \quad (6)$$

$$db = (r-1)(c-1) \quad (7)$$

$$D_n = \max|F_x(x_i) - S_n(x_i)| \quad (8)$$

2.6 RMSE Method

To measure the level of error in predictions, the RMSE comparison tool is used to assess the accuracy of a model or a data set (9) [10],[18].

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - x_i)^2} \quad (9)$$

It requires several key parameters. Field acquisiton wind speed data (y_i), which represent filed measurements serving as the benchmark for evaluation. ERA-5 wind speed values (x_i) generated by a model. The total number of observations (n) is counts of data in August to September acquisition time range. The error rate of the wind speed comparison data can be observed in Table 2 [10,19].

Table 2: Interpretation of RMSE

RMSE	Error Rate
0%-29.9%	Low
30%-59.9%	Moderate
60%-89.9%	High
>90%	Very High

2.7 Wind Turbine Specifications

The specifications for the wind turbines that can be used include parameters such as turbine power output, rotor diameter, turbine height, wind speed, and more[20]. Two types of turbines have been selected for analysis: the Aventa AV-7 and the Antaris 12 illustrated in Figure 2. The details of these turbines will be analyzed and summarized in Table 3.

Table 3: Wind Turbine Specifications [21]

No	Specifications	Aventa AV-7	Antaris 12	Unit
1	Hub Height	18	30	m
2	Power Wind Turbine	6.2	12	kW
3	Rated Wind Speed	6	6	m/s
4	Cut-in Wind Speed	2	2.5	m/s
5	Rotor Diameter	12,8	5.8	m

(a) (b)

Figure 2: Wind turbine: (a) Aventa AV-7 and (b) Antaris 12

3.0 RESULT AND DISCUSSION

3.1 Comparison of Wind Data

The results of the comparison between wind speed data from secondary sources (ECMWF) and primary field data collected using the Davis Pro 2 instrument, were obtained over one month from August 19, 2024, to September 18, 2024, at a reference height of 10 meters, as shown in Figure 3.

Based on Figure 3, the comparison of wind speed data is conducted to determine the accuracy value as a calibration factor, which results in a low error rate, as shown in the data presented in Table 4.

Table 4: Results of wind speed data comparison

Parameter	Result	Unit
Average of Primary Data	2.29	m/s
Average of Secondary Data	2.29	m/s
Calibration Factor	1.7	
RMSE	0%	

The results of the comparison between the two wind speed data sets in Table 4, calculated using the RMSE method with the equation (9), show an RMSE value of 0%. As indicated in Table 2, this RMSE result is categorized as a small error. The average wind speed from ECMWF over 20 years is 2.53 m/s, which is significantly lower when compared to the average wind speed of 6 m/s found in studies along the western coast of Lampung.

The graph in Figure 3 shows a significant difference between the two data sources; however, both data sets align in certain aspect, which reinforces the reliability of the data. The primary wind speed data captures higher peaks, allowing for better identification of variations in wind speed. After that, the wind speed distribution at the reference height of 10 m is used as data to validate the probability distribution, as illustrated in Figure 4.

3.2 Validation of Wind Distribution Probability Data

Validation of wind speed distribution data at a height of 10 m is carried out to ensure that the processed wind speed distribution is suitable for further analysis by satisfying certain criteria in the distribution data testing. The Chi-Square method, as presented in equation (6), is applied to the random variable of the wind speed data, while the Kolmogorov-Smirnov method, as detailed in equation (7), is used for the cumulative density function of the wind speed data. The results of this validation are displayed in Table 5.

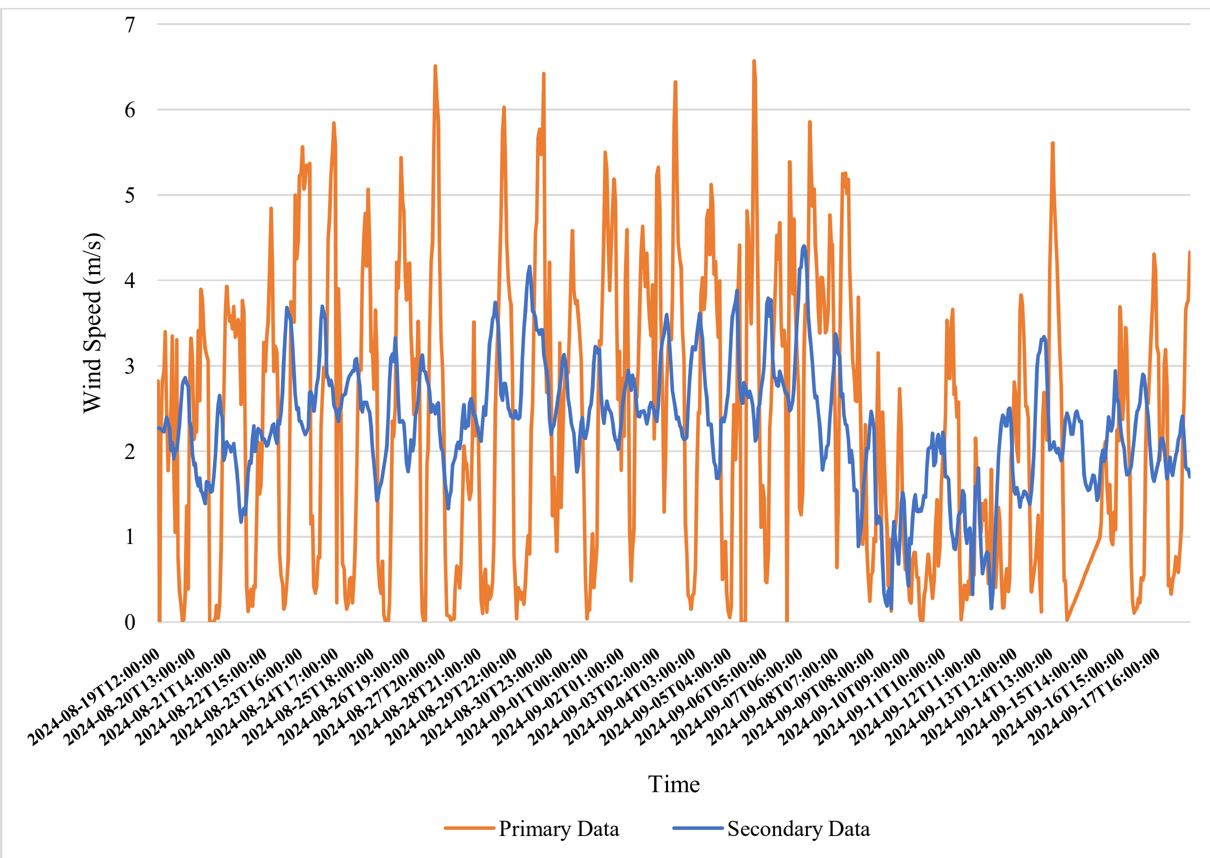

Figure 3: Comparison of primary and secondary wind speed data

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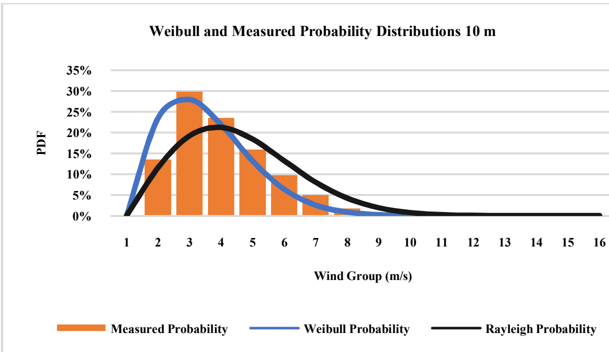

Figure 4: Probability distribution at a height of 10 meters

Table 5: Results of Data Validation on Distribution

Method	Distribution	
	Weibull	Rayleigh
Chi-Square	0.11	0.42
Kolmogorov-Smirnov	0.82	0.84

Based on the results in Table 5, the Chi-Square method for both distributions is acceptable, as the value of($X^2 table$)is 4.6, and the criterion is met since$X^2 count < X^2 table$. The results of the Kolmogorov-Smirnov test showed a test statistic of 0.82 for the Weibull distribution and 0.84 for the Rayleigh distribution. In each validation test, the Weibull distribution was chosen for data processing because it had the lowest value in all validation tests, which is anticipated to provide the power output for the wind turbine.

3.3Wind Speed Distribution Data

The wind speed histogram and probability density function utilize the Weibull distribution as described in equation (1) and the Rayleigh distribution as outlined in equation (2) at various heights, maximizing the height of the wind turbine over 20 years from 2004 to 2024. This is illustrated in Figure 5 at a height of 18 m and in Figure 6at a height of 30 m.

The Weibull probability distribution shows a probability of 97.52% for wind speeds between 2 and 18 m/s, as illustrated in Figure 5. In contrast, Figure 6 indicates a Weibull probability of 98.05% for the same wind speed range, which is necessary for activating the wind turbine and enabling the conversion of wind energy into electrical power.

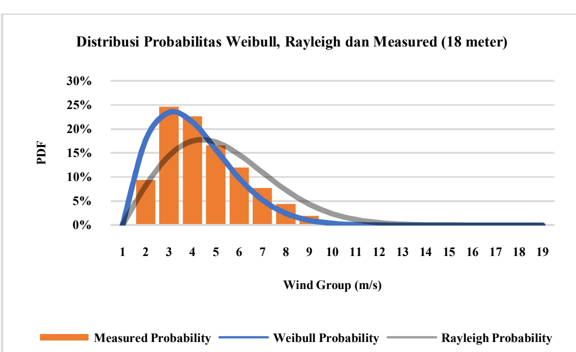

Figure 5: Probability distribution at a height of 18 meters

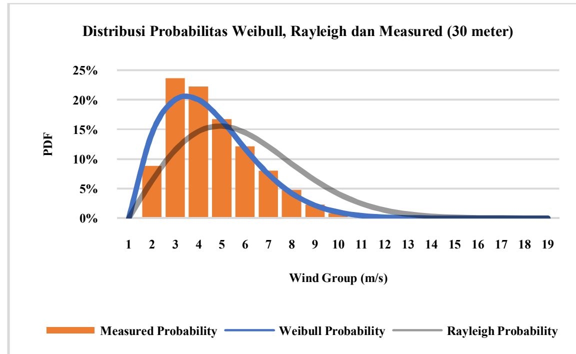

Figure 6: Probability distribution at a height of 30 meters

3.4 Wind Turbine Power

Table 6 illustrates the wind speed categories, for example, 1 m/s refers to a wind speed of 1 m/s, while a wind speed of 3 m/s indicates wind speeds ranging from above 2 m/s to 3 m/s. The probability reflects the likelihood of each wind speed category occurring over a year. The probability function is applied to the turbines used, namely the Aventa AV-7 and Antaris 12, which have different power outputs and heights based on the annual power output curves of the wind turbines.

Table 6 presents the annual energy output of wind turbines based on wind speed probability using the Weibull distribution. The Aventa AV-7 wind turbine, operating at a height of 18 meters, generates an annual energy output of 11,096.29 kWh, while the Antaris 12 kW wind turbine, positioned at a height of 30 meters, produces an annual energy output of 6,903.78 kWh. In determining the annual power output of the wind turbine is used Equation (10).

Therefore, based on the analysis, the Aventa AV-7 wind turbine emerges as the optimal choice for renewable energy solutions at Pantai Manna, delivering the highest annual energy output. The selection of the Aventa AV-7 directly translates to a greater potential for sustainable energy generation, contributing significantly to the region's renewable energy.

3.5 Electricity Energy Demand

This research focuses on analyzing the electricity demand and the number of users in Manna District over a one-year period. The data used in this study is sourced from the statistical records provided by PLN Bengkulu and the Central Bureau of Statistics (BPS) for Manna District. Manna District consists of 18 villages, some of which still experience limited access to electricity, as highlighted in Table 7.

The data from Table 6 provides information on the number of household electricity users, while Table 7 presents the total electricity consumption for various types of buildings and facilities within the district. By combining these data sets, researchers can assess the overall electricity demand and identify areas that require infrastructure improvements. The analysis reveals that the total electricity demand for Manna District amounts to 7,343,699.02 kWh per year.

Understanding the electricity demand in Manna District is crucial for future planning and development. The findings from this research can help policymakers and local authorities make informed decisions on expanding the electricity grid, enhancing energy efficiency, and ensuring equitable access to electricity for all residents.

Table 6: Annual power output of wind turbines

Wind Group (m/s)	Aventa AV - 7			Antarias 12		
	Probability (%)	Power (kW)	Annual Yield (kWh)	Probability (%)	Power (kW)	Annual Yield (kWh)
1	17.80%	0	0	14.35%	0	0
2	23.47%	0.10	205.56	20.05%	0.01	17.56
3	21.46%	0.70	1,316.03	20.01%	0.10	175.31
4	15.76%	1.50	2,071.06	16.47%	0.50	721.59
5	9.77%	3.50	2,652.48	11.74%	1.20	1,233.68
6	5.23%	5.80	2,658.78	7.40%	2.10	1,361.93
7	2.46%	6.20	1,335.27	4.19%	3.25	1,193.29
8	1.02%	6.20	555.33	2.15%	5.11	961.61
9	0.38%	6.20	205.83	1.00%	7.10	623.75
10	0.13%	6.20	68.34	0.43%	9.50	356.53
11	0.04%	6.20	20.41	0.17%	11.10	163.44
12	0.01%	6.20	5.50	0.06%	12.11	64.42
13	0%	6.20	1.34	0.02%	12.11	21.49
14	0%	6.20	0.30	0.01%	12.11	6.63
15	0%	6.20	0.06	0%	12.11	1.90
16	0%	6.20	0.01	0%	12.11	0.50
17	0%	6.20	0	0%	12.11	0.12
18	0%	6.20	0	0%	12.11	0.3
Total			11,096.29			6,903.78

Table 7: The total energy needed for Manna District

No	Building	Amount	Energy needs (kWh)
1	Mosque/Church	38	157,320.55
2	School	24	99,560.35
3	Hospital	3	82,800,29
4	Bank	1	9,881.20
5	Hotel	1	8,302.33
6	House	5,310	6,918,554.18
7	Other	9	67,480.10
Total			7,343,699.02

Source: PLN and the Central Statistics Agency in Bengkulu [22,23]

3.6 Wind Turbine Needs

In the determination of the turbines to be used, it is established that the total power generated will be 30% of the output of the wind turbines, which indicates the number of wind turbines that will be employed.

Table 8: Distribution of supplied electricity

Total Electricity(kWh)	70% from PLN(kWh)	30% from Wind Turbines(kWh)
7,343,699.02	5,140,589.31	2,203,109.71

Table 9: Number of wind turbines required

30% from Wind Turbines(kWh)	Annual Year Aventa AV-7(kWh)	Number of Wind Turbines
2,203,109.71	11,096.29	199

It is indicated in Table 8 that the electricity supplied from wind turbines does not account for 100%, as PLN supplies 70% of the total electricity used, which amounts to 5,140,589.31 kWh/years. To minimize the reliance on a large number of wind turbines, the electricity generated from wind turbines is set to 30% of the total electricity consumption, equating to 2,203,109.71 kWh/years. Consequently, the total electricity requirement for users in Manna District is 7,343,699.02 kWh/years.

Based on the total number of wind turbines to be used in Table 9, it can be determined that the total energy requirement of 30% from wind turbines is 2,203,109.71 kWh/year for Manna District, using a wind turbine with a significant annual power output, specifically the Aventa AV-7 turbine, which produces 11,096.29 kWh/year. To find out the number of turbines needed, Equation (12) is used. Therefore, Manna District requires 199 wind turbines to provide 30% of the total electricity consumption in the district. This calculation reflects the district's energy demand and the power output of turbines.

3.7 Number of Wind Turbines Used Efficiently

To enhance the efficiency of the number of wind turbines designated for wind farm land use and to ensure that all turbines remain operational, a 6% reduction in the output from the wind turbines has been applied.

Table 10: Efficiency of the number of wind turbines

6% from Wind Turbines(kWh)	Annual Year Aventa AV-7(kWh)	Number of Wind Turbines
440,621.94	11,096.29	40

The results of the wind turbines' efficiency is shown in Table 10. Table 10 details the use of 40 Aventa AV-7 wind turbines. A 6% output reduction was factored in, impacting the turbines' performance. This resulted in a total energy production of 440,621.94 kWh/years, equivalent to 440 MWh. It used the Aventa AV-7 wind turbine, which generates an output of 11,096.29 kWh/years.

4.0 CONCLUSION

The analysis of wind speed data around Manna Beach revealed an average wind speed of 2.5 m/s, peaking at 10.01 m/s. The annual electricity requirement for the Manna sub-district is 440 MWh, highlighting the region's energy needs. To fulfill 6% of this annual demand, the study suggests utilizing the Aventa AV-7 wind turbine, which produces 11,096.29 kWh per unit annually. Consequently, approximately 40 of these turbines would be necessary to meet the targeted electricity contribution. Future studies can be explored the feasibility of hybrid energy systems, combining wind power with other renewable sources to optimize electricity generation in the Manna sub-district given the fluctuating wind speeds and potential for increased energy demand. Additionally, a comprehensive economic analysis considering the long-term maintenance costs and environmental impact of deploying 40 Aventa AV-7 wind turbines should be conducted to ensure sustainable and cost-effective energy solutions.

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