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Implementation of vertical axis wind turbine on renewable energy based self-sustaining public street lighting system

Dewi Indriati Hadi Putri, Muhammad Praja Dewanata, Arditya Baskara Mahbubi, Liptia Venica, Muhammad Rizalul Wahid

Department of Mechatronics and Artificial Intelligence, Universitas Pendidikan Indonesia
Jl. Dr. Setiabudi No. 229, Bandung, West Java, 40154, Indonesia

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ABSTRACT

Kutamanah village, located in Sukasari Sub-district, Purwakarta District, faces limited electricity networks in strategic locations such as connecting roads between settlements, which impacts residents' safety and activities, especially at night. To overcome this problem, a program to utilize the potential of wind energy with a Vertical Axis Wind Turbine (VAWT) as a source of electrical energy for Public Street Lighting (PJU) was carried out. This activity was carried out through several stages, namely surveying the location of VAWT and PJU placement points, assembling VAWT and PJU, training and mentoring in implementation as appropriate technology that local residents can utilize. The system is designed to produce stable electrical power by utilizing the average wind speed that suits local conditions, which is 8.3 m/s. The implementation results show that this system is able to produce a peak voltage of 17.48 V and a current of 3.2 A so that the power generated reaches 54.4 W, the power is sufficient to support the operation of Public Street Lights with 50 W 12 V power specifications. This program contributes to improving community safety and mobility while supporting the use of sustainable renewable energy at the village level.

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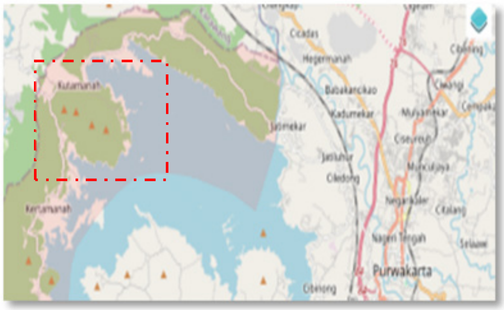
1. INTRODUCTION

The village of Kutamanah is located in the Sukasari sub-district, Purwakarta Regency, West Java Province, Indonesia. Geographically, its topography is dominated by hills and gently sloping plains, with a regional incline of less than 15 degrees. The total area of Kutamanah Village reaches 30.10 km^2, making it one of the largest villages in this sub-district, as shown in Figure 1.

Based on its geographical conditions, which consist of hills and plains, as well as its moderate elevation, Kutamanah Village has the potential to experience decent wind flows for utilizing wind energy as an alternative energy source, according to data obtained from AccuWeather.

The wind speed data from Figure 2 indicates that this location is one of the ideal sites for developing a lighting system based on renewable energy. The project site is in Kampung (Kp) Pasirkole, RT. 01/RW. 02, Kutamanah Village, Sukasari Sub-district, 41116. Kp Pasirkole directly borders Mount Parang and Jatiluhur Lake, earning it the nickname "the village of a thousand rocks," as shown in Figure 3.

Corresponding Author: **Dewi Indriati Hadi Putri**: Tel. +62 22 2013163 | E-mail: dewiindri@upi.edu



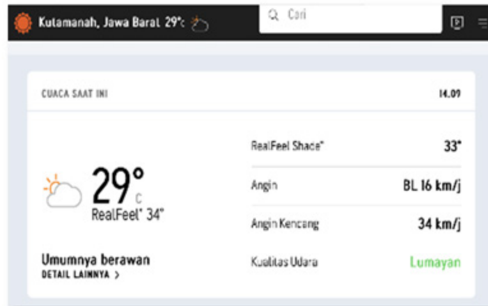


Figure 1. Map of Kutamanah Village
Figure 2. Information on wind conditions in the Kutamanah area (https://www.accuweather.com/)

Figure 3. Project site: (a) Mount Parang; (b) Lake Jatiluhur

Based on the survey conducted by the community service team on July 11, 2024, and interviews with village officials, Mr. Muhammad Sueb (village secretary) and Mr. Sarmun Gumelar (head of RW 02), the identified issue in Kutamanah Village is that it is a remote area with difficult access due to rocky and damaged roads. As a result, the village faces challenges in providing Public Street Lighting (PJU), especially along main roads and pathways connecting residential areas (Irwan, 2024). Currently, lighting is only available within individual homes, which are located at a considerable distance from the main road. The lack of lighting infrastructure leads to low nighttime visibility, impacting community safety and mobility, ultimately reducing economic and social activities at night. Several studies have shown that access to adequate street lighting can improve the quality of life by enhancing security and extending productive hours (Agustina, 2023; Aini et al., 2024; Aryanto, 2023). Therefore, an innovative and sustainable solution is needed to address this issue.

As a solution, the community service team proposes the implementation of Appropriate Technology (TTG) through a renewable energy-based street lighting system using a Vertical Axis Wind Turbine (VAWT). This technology is chosen for its efficiency in low-to-moderate wind conditions, which align with the geographical characteristics of Kutamanah Village. According to available data, the average wind speed in Purwakarta Regency ranges between 7.6–10.6 km/h or approximately 2.1–2.9 m/s (Weatherspark, 2024). This wind speed is close to the minimum requirement for VAWT operation, which is around 3 m/s for effective performance (Rawal et al., 2023). Additionally, VAWT has a more flexible design compared to Horizontal Axis Wind Turbines (HAWT), allowing installation in various locations without requiring large land areas (Hijazi et al., 2024). With the implementation of this system, the community is expected to gain access to a more stable and environmentally friendly energy source for Public Street Lighting (PJU).

The use of VAWT as an alternative energy source has been widely studied and proven effective in various applications. Several studies indicate that this technology has good energy conversion efficiency, particularly in urban areas and low-wind-speed conditions (Altmimi et al., 2021; Rajpar et al., 2021; Santamaría et al., 2022). Moreover, the application of wind turbines in street lighting systems has been implemented in various countries, such as Canada, as a sustainable solution to reduce reliance on fossil fuels and improve electricity access in remote areas (Timalsina et al., 2024; Vajari et al., 2024). Therefore, implementing a vertical-axis wind turbine system in Kutamanah Village is considered an appropriate solution to address the street lighting issues in the area.

2. METHODS

The installation program for the Vertical Axis Wind Turbine (VAWT) in Kp. Pasirkole, RT 01/RW 02, Kutamanah Village, Purwakarta Sub-district, follows a comprehensive strategy involving the local community. The project is led by the Head of Kutamanah Village, Mr. Asep Samsudin, as the person in charge, assisted by the Village Secretary, the Head of RW 02, Didin Jaenudin as the Head of RT 015, village youth, students, and the community service team. The team consists of three village officials and 17 implementation team members, making a total of 20 participants from both the village and the community service team.

This program is carried out over eight months. The stages of the community service activities include site surveys and location determination, assembly and testing, installation and implementation, training and mentoring, as well as evaluation and monitoring, as outlined in Table 1.

Table 1. Community service program implementation timeline

Stages	Activities	Time
Survey and Site Determination	Initial survey collects wind speed data, compares locations, and determines optimal points	July 2024
Assembly and Testing	VAWT design, VAWT assembly, system testing and performance simulation	August 2024
Installation and Implementation	VAWT installation, system testing, and operational verification	September 2024
Training & Mentoring	Technical training for the community and maintenance assistance	October 2024
Evaluation & Monitoring	Electric power measurement, performance monitoring, and technical constraint analysis	November 2024

3. RESULTS AND DISCUSSION

Results

Survey and location determination

The community service activities begin with a site survey to determine areas with optimal wind potential. Several villages were considered as candidate locations for this project, including Kutamanah Village and Cileungsing Village, as both are remote areas with difficult access conditions. However, based on observations and data obtained from the AccuWeather website, as shown in Figure 4, Kutamanah Village exhibits stronger wind characteristics compared to Cileungsing Village, with wind speeds reaching 30 km/h. Additionally, the presence of hilly terrain and a nearby lake further enhances its potential for generating electricity through VAWT.

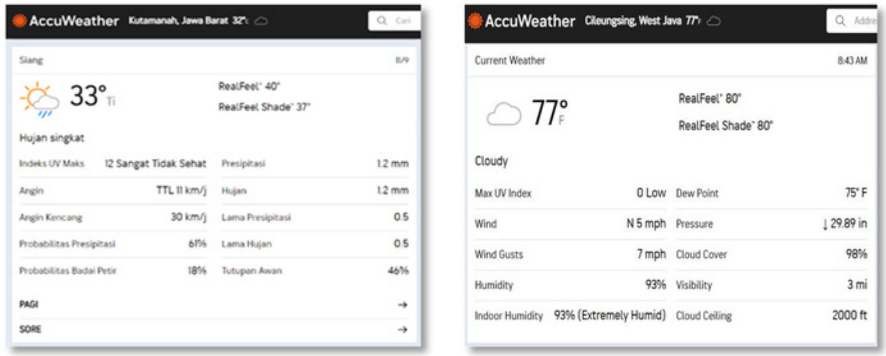


Figure 4. Wind speed comparison data. Kutamanah Village with Cileungsing Village

The next step in determining the project location involved discussions between the team and local village officials to obtain permission and identify the optimal site for installing the VAWT, as shown in Figure 5. After discussions and an analysis of street lighting needs, it was decided to install the VAWT at a point between the main road and residential areas that currently lack Public Street Lighting (PJU).

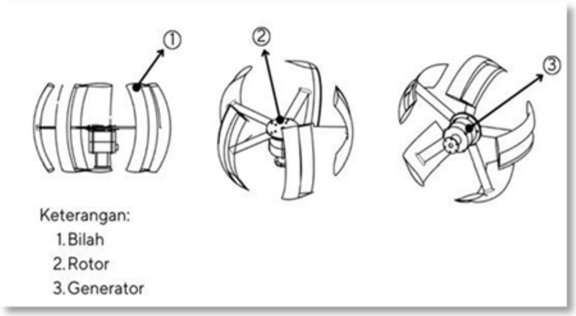
Figure 5. Licensing & discussion on determining the optimal location for installing VAWT

Assembly and testing

As an initial step before assembly, the implementation team—consisting of the executive leader, technical personnel, and evaluation team—designed the VAWT system, as shown in Figure 6. The main equipment used includes (1) turbine blades, (2) a rotor, and (3) a 500-watt, 12-volt generator. Additionally, other supporting components, as illustrated in the schematic diagram in Figure 7, include (2) a 36Ah lithium battery, (3) a charge controller, and (4) a 50-watt, 12-volt Public Street Lighting (PJU) lamp.

Based on Figure 7, the system operates by utilizing wind energy to drive the turbine blades, causing the rotor to spin the generator and produce electricity. The generated electricity is then directed to the charge controller, which regulates the charging process for the 36Ah, 12V lithium battery to prevent overcharging or over-discharging. The stored energy in the battery is used to supply voltage to the 50W, 12V Public Street Lighting (PJU) lamp at night.

VAWT technology was chosen for its efficiency in low-to-moderate wind conditions. This system works by capturing the kinetic energy of the wind, converting it into mechanical energy through the rotor, and then transforming it into electrical energy using the generator. The key advantage of VAWT is its ability to capture wind from multiple directions without requiring a yaw mechanism or a system that allows the wind turbine nacelle (housing) to continuously adjust to face the dominant wind direction for optimal energy production. Additionally, VAWT offers ease of maintenance (Absor et al., 2023; Cazzaro et al., 2023; Mahmuddin et al., 2019).



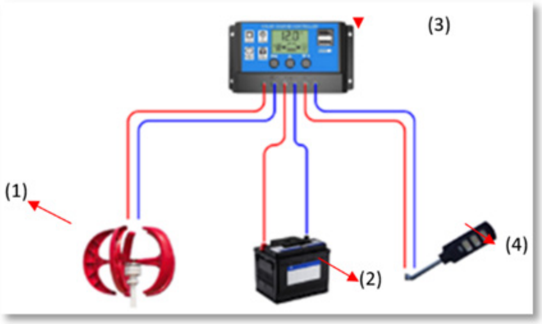


Figure 6. VAWT building blocks
Figure 7. Schematic diagram of VAWT implementation

The next step involves assembling the VAWT by attaching each blade to the rotor and generator. Once the blade assembly is complete, the PJU lamp is installed on a pole integrated with the VAWT, as shown in Figure 8.

Figure 8. (a) Blade installation; (b) Blade assembly with rotor and generator; (c) Lamp cable assembly; (d) Lamp assembly with VAWT

Installation and implementation

At the implementation stage, the VAWT is installed at the predetermined location. This process includes setting up the pole, installing the power transmission system, and connecting it to the energy storage system. An operational test is conducted to ensure that the system functions properly and can provide a stable energy supply. Additionally, verification and validation of system performance are carried out to confirm that this technology meets the lighting needs of Kutamanah Village, as shown in Figure 9.

Figure 9. (a) Installation of PJU cables to poles; (b) Installation of power transmission systems; (c) Installation of VAWT and PJU; (d) Validation of system performance of installed PJU

After the installation process is complete, the program moves to the evaluation and periodic monitoring phase. The implementation team is responsible for overseeing the operational performance of the VAWT to ensure its capacity to generate a stable power supply. This evaluation involves systematically measuring electrical output and assessing the condition of the generator and energy storage battery. If any technical issues arise, trained community members are expected to have the necessary skills to perform basic repairs independently.

Training and mentoring

As a continuation of this program, training is first provided to village officials on technical guidelines for VAWT maintenance and troubleshooting. This is followed by a community outreach session on the use of VAWT for public street lighting (PJU) and basic maintenance practices. The training is conducted alongside the official opening of the community service activities in Kutamanah Village, as shown in Figure 10.

Figure 10. Opening of community service activities and socialization of VAWT utilization for PJU with village officials, local residents and students

Evaluation and monitoring

The street lighting powered by VAWT has been successfully installed and is functioning well, providing illumination at night for the residents. The wind speed is sufficient to generate adequate energy for the battery, ensuring reliable operation, as shown in Figure 11.

Figure 11. (a) Complete design of VAWT-based PJU,
(b) Condition of VAWT-based Public Street Lighting at Night

After the installation process is complete, the program transitions to the evaluation and periodic monitoring phase. The implementation team is responsible for overseeing the operational performance of the VAWT to ensure its capacity to generate stable power. This evaluation includes systematic measurements of electrical output and assessments of the generator and energy storage battery. If technical issues arise, trained community members are expected to have the necessary skills to perform basic repairs independently.

The electrical output measurement for powering the PJU lamp was conducted five times within a time range from 08:00 to 17:00 WIB, as shown in Table 2. The measured current values ranged between 3–3.2 A.

Table 2. Wind speed and voltage measurement data on VAWT

Hour	Wind speed					Avg. (m/s)	Voltage					Avg. (V)
	Test 1 (m/s)	Test 2 (m/s)	Test 3 (m/s)	Test 4 (m/s)	Test 5 (m/s)		Test 1 (V)	Test 2 (V)	Test 3 (V)	Test 4 (V)	Test 5 (V)	
08.00	3.1	3.3	3.0	3.2	3.1	3.14	14.9	15.5	14.2	15.0	14.7	14.86
09.00	1.95	2.0	1.85	1.9	2.1	1.96	3.71	3.9	3.5	3.8	4.0	3.78
10.00	2.41	2.5	2.3	2.4	2.6	2.44	7.0	7.2	6.8	7.1	7.3	7.08
11.00	2.48	2.6	2.4	2.5	2.7	2.54	7.63	7.9	7.5	7.8	8.0	7.76
12.00	3.2	3.4	3.1	3.3	3.5	3.3	16.38	16.9	15.8	16.5	17.0	16.51
13.00	3.27	3.5	3.2	3.4	3.6	3.39	17.48	17.30	16.9	17.5	16.9	17.21
14.00	2.96	2.8	2.6	2.7	2.9	2.74	9.73	10.0	9.2	9.8	10.2	9.78
15.00	2.63	2.7	2.5	2.6	2.8	2.66	9.1	9.4	8.8	9.2	9.5	9.2
16.00	2.67	2.8	2.6	2.7	2.9	2.74	9.52	9.8	9.1	9.5	9.9	9.56
17.00	2.24	2.3	2.1	2.2	2.4	2.26	5.62	5.8	5.3	5.9	5.9	5.64

The data in Table 2 is presented in the form of a graph that has variations in wind speed changes that occur in Kutamanah Village. The measurements produced data fluctuate because the wind conditions in Kutamana Village are unstable.

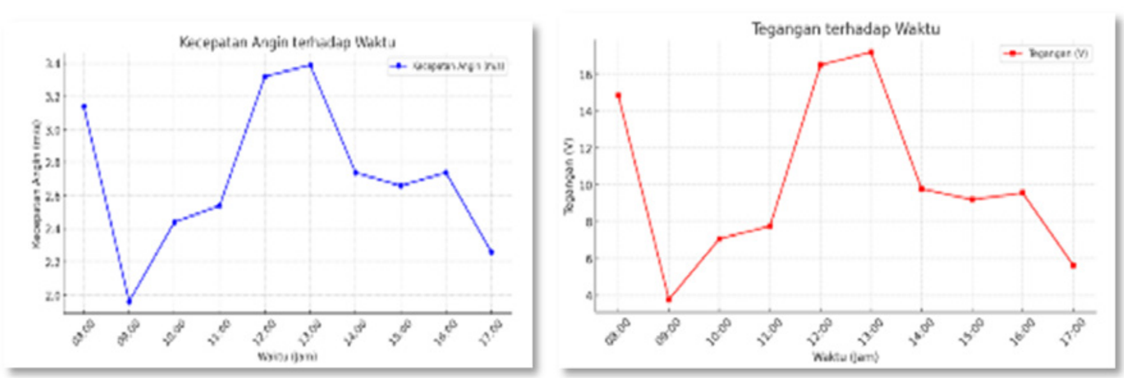


Figure 12. (a) Wind speed measurement graph; (b) Voltage measurement graph obtained by VAWT

Based on the graph above, it can be observed that wind speed tends to fluctuate throughout the day, with the highest values occurring around 12:00–13:00, averaging 3.39 m/s. The higher wind speeds during this time directly impact the increase in wind-generated voltage output. From the relationship pattern between wind speed and voltage, it can be concluded that the voltage generated by the VAWT is highly dependent on wind speed variations. This means that the tested VAWT system operates more effectively at medium to high wind speeds, whereas at lower speeds, the generated voltage is not yet optimal for meeting larger electricity demands.

Using the data from Table 2, the output power of the VAWT can be calculated. Given the measured current of 3.2 A, we can use the following formula:

$$P = V \times I$$

with:

P = electrical power (watts)

V = voltage (volts)

I = current (A)

Table 3. Output power calculation on VAWT

Hour	Average Voltage (V)	Output Power (Watts)
08.00	14.86	47.55
09.00	3.78	12.10
10.00	7.08	22.66
11.00	7.76	24.83
12.00	16.51	52.83
13.00	17.21	55.07
14.00	9.78	31.30
15.00	9.2	29.44
16.00	9.56	30.59
17.00	5.64	18.05

Based on the power calculation obtained from the VAWT system, it turns out that it is not yet sufficient to power the PJU lamp throughout the entire day. Only between 12:00–13:00 WIB does the generated power meet the 50W requirement for the PJU lamp. Therefore, the team added a backup battery to ensure that the lamp remains operational.

Discussion

The implementation of VAWT in the independent street lighting system based on renewable energy in Desa Kutamanah has shown positive results. The designed system is capable of generating up to 54.4 W of electrical power at its peak voltage of 17.48 V. This power is sufficient to support the operation of a 50W PJU lamp. With this success, the main objective of the community service program—enhancing public safety and mobility through street lighting—has been achieved. Additionally, this technology implementation supports the use of environmentally friendly energy at the village level, reduces reliance on conventional power grids, and introduces sustainable energy alternatives to the residents of Kp. Pasirkole RT 01/RW 02.

A comparative study with similar research indicates that hybrid energy systems in remote areas can enhance energy resilience and provide significant benefits to local communities (Kabeyi & Olanrewaju, 2022; Timalsina et al., 2024). Furthermore, VAWT performs well at medium wind speeds, which align with the geographical conditions of Desa Kutamanah (Mahmuddin et al., 2019). Another study highlights that the use of wind deflectors can improve VAWT efficiency (Rajpar et al., 2021), although this particular program has not yet implemented such technology. Based on these comparisons, it can be concluded that the implementation of VAWT in Kp. Pasirkole RT 01/RW 02, Desa Kutamanah, aligns with current trends in renewable energy development. However, further improvements can be made in terms of energy efficiency and storage capacity to optimize lighting availability throughout the night.

The impact of this technology is significant in improving road visibility at night, as well as enhancing the safety and mobility of residents, based on interviews conducted with the community of Kp. Pasirkole RT 01/RW 02, Desa Kutamanah. Additionally, this community service program provides benefits in the form of human resource development through training and mentoring for local residents, equipping them with technical knowledge of the VAWT system, including maintenance procedures. As a result, the long-term sustainability of this system can be maintained without complete dependence on external experts. Moreover, the program offers tangible benefits to the local community in both technical and social aspects. The implementation not only focuses on infrastructure development but also emphasizes community empowerment, enabling residents to manage and maintain this technology independently.

4. CONCLUSION AND RECOMMENDATIONS

This community service program has successfully achieved its primary objectives, as evidenced by improvements in participants' knowledge and skills through pre-test and post-test assessments conducted with 20 participants. Before the training, the average understanding of VAWT technology and renewable energy among participants was scored at 43.5 in the pre-test, while the post-test score increased to 81.15. Based on these results, the participants' understanding improved by 86.55%, demonstrating the effectiveness of the program in enhancing their skills and knowledge regarding VAWT and its maintenance. From the perspective of appropriate technology (TTG) implementation, the installed VAWT system was able to generate a maximum electrical power output of 54.4 W at a measured voltage of 17.48 V. Power measurements were conducted under various wind speed conditions, indicating that optimal power output was achieved at a wind speed of 3.39 m/s. The impact of this electricity supply includes improved access to public street lighting over a 100-meter stretch in a crucial area—the main road leading to the residential area. This improvement enhances night-time visibility, security, and mobility for local residents, aligning with the program's goal of fostering sustainable and self-sufficient energy solutions in remote communities.

The main shortcoming of this community service program is the absence of a written training module, as the training was conducted verbally and through hands-on practice. For future community engagement programs, it is recommended to develop a comprehensive written training module designed to empower the community in maintaining and operating the system independently. Additionally, future improvements should focus on increasing energy storage capacity to optimize power usage, conducting further research to enhance VAWT design efficiency, and implementing regular monitoring of turbine performance and step-up modules to ensure long-term operational efficiency and facilitate early maintenance detection. Moreover, the program should be expanded to other villages with strong wind potential, using thorough preliminary surveys to assess location suitability. Lastly, there is an urgent need for further research aimed at optimizing turbine design and improving energy conversion efficiency. This would enhance adaptability to wind speed fluctuations and contribute to the advancement of renewable energy solutions in Indonesia.

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