ESIC2024 Posted: 16/10/2024

The Integration of Solar and Wind Energy to Enhance Optimization and Efficiency of Renewable Energy

Zuraidah Tharo[1], Supiyandi[2], Haris Gunawan[3]

[1]Department of Electrical Engineering, Fakultas Sains dan Teknologi, Universitas Pembangunan Panca Budi, 20128 Medan, Indonesia
[2]Department of Computer Engineering, Fakultas Sains dan Teknologi, Universitas Pembangunan Panca Budi, 20128 Medan, Indonesia
[3]Department of Electrical Engineering, Sekolah Tinggi Teknologi, Sinar Husni, 20373 Medan, Indonesia
Email: zuraidahtharo@dosen.pancabudi.ac.id

Abstract

The integration of solar and wind power offers significant potential to improve the efficiency and optimization of renewable energy. These two energy sources complement each other, with solar power generating energy during the day, while wind power can be produced both day and night, depending on weather conditions. By combining these two sources, we can address the instability of renewable energy supply, which often occurs due to dependence on a single type of energy source. This hybrid system can enhance the availability of more stable and sustainable energy while reducing dependence on fossil fuels. The use of appropriate technologies, such as energy storage and intelligent control systems, enables improved efficiency and optimization in the management of energy from these sources. This study will discuss the design, benefits, and challenges in integrating solar and wind power as a solution to optimally and efficiently increase the utilization of renewable energy. Furthermore, this research evaluates the contribution of solar and wind power integration in meeting energy needs in areas that are difficult to reach by conventional electrical grids.

Keywords: integration; hybrid; efficiency; optimization.

I In recent decades, the demand for sustainable and environmentally friendly energy has become more urgent due to the increase in global energy consumption and the environmental impact of fossil fuel use.[1] Renewable energy, such as solar and wind power, has emerged as a primary solution to reduce carbon emissions and dependence on conventional energy sources.[2] However, the main challenge of renewable energy sources is their fluctuating and unstable nature, as energy availability depends on weather conditions and time.[3]

Solar power, for instance, can only be generated during the day and depends on the intensity of sunlight, while wind power fluctuates with wind speed and direction.[4] These fluctuations create challenges in ensuring a consistent and reliable energy supply.[5] Therefore, the integration of solar and wind power into a single hybrid system is one solution that can improve the stability and efficiency of renewable energy.[6]

By combining these two energy sources, we can complement the weaknesses of each.[7] When solar energy decreases, wind power may compensate for the shortfall, and vice versa.[8] The use of this hybrid system not only increases energy availability but also enhances the efficiency in utilizing natural resources.[9]

1.1 Solar Energy

Solar energy is derived from the sun's radiation and can be converted into electricity or heat.[10] Here's an overview:

Types of Solar Energy Systems

a. Photovoltaic (PV) Systems:

How It Works: Solar panels made of semiconductor materials (like silicon) convert sunlight directly into electricity through the photovoltaic effect.

Applications: Residential solar panels, commercial solar arrays, and solar farms.

b. Solar Thermal Systems:

How It Works: These systems use sunlight to heat a fluid, which then transfers the heat to a water tank or a heat exchanger.

Applications: Solar water heaters, solar space heating, and industrial processes.

c. Concentrated Solar Power (CSP):

How It Works: CSP systems use mirrors or lenses to concentrate sunlight onto a small area. The concentrated light heats a fluid, which then drives a turbine to generate electricity.

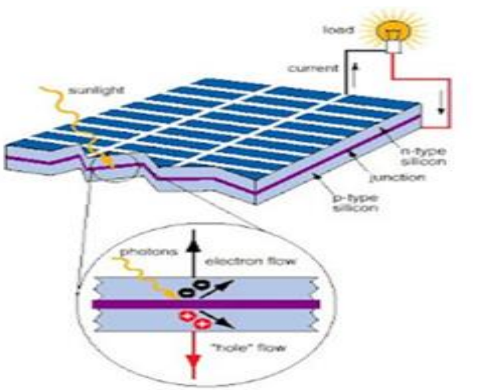

Figure 1. Principle of Solar Cells

Benefits of Solar Energy[10]

a. Renewable: Solar energy is abundant and replenished naturally.

b. Sustainable: Reduces reliance on fossil fuels and helps mitigate climate change.

c. Low Operating Costs: After installation, solar energy systems have minimal operational costs.

d. Energy Independence: Reduces reliance on external energy sources and enhances energy security.

e. Environmental Impact: Produces no direct emissions or pollutants during operation.

Challenges[11]

a. Intermittency: Solar energy generation depends on sunlight, which varies by location and time.

b. Initial Costs: Installation costs can be high, though they are decreasing with technological advancements and incentives.

c. Space Requirements: Solar panels require space, which might be a limitation in densely populated areas.

Technological Advancements

a. Improved Efficiency: Advances in PV technology, such as higher-efficiency cells and better materials.

b. Energy Storage: Development of better batteries and storage solutions to store excess solar energy.

c. Integration: Enhanced methods for integrating solar power with the grid and other energy systems.

The power produced by a solar power plant can be calculated using the following equation:

$$P_{out} = A \times G \times \eta \times D \quad (1)$$[12]

1.2 Wind Energy

The wind is air that moves from areas of high pressure to low pressure. Light air moves upwards towards colder areas so that the air will become cold and turn heavy again, then the cold air will circulate downwards, resulting in air circulation and air movement called wind energy.

When the wind blows, it is accompanied by kinetic energy (movement) which can do work.

Kinetic energy is energy due to a mass having a relative speed, for example a moving car or a rotating power wheel. Wind energy resulting from wind movement can be converted into mechanical energy using a windmill or into electrical energy using a wind turbine which is also called a Wind Energy Conversion System (SKEA). The amount of energy that can be transferred to the rotor depends on the air density, area and wind speed. The kinetic energy for a wind mass m moving with speed v is converted into shaft energy. It can be seen from the following equation:

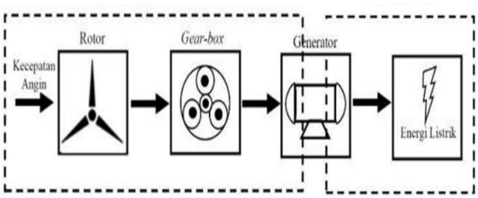

Figure 2. Principle of Wind Energy

Then the output power of the wind power plant can be calculated using the following equation:

$$P = \frac{1}{2}\rho A v^3 Cp \qquad (3)[13]$$

1.3 Hybrid Energy

A solar-wind hybrid power plant is a system that combines two renewable energy sources, namely solar power and wind power, to produce electricity. This combination aims to increase the efficiency and reliability of electricity supply, by exploiting the advantages of each energy source and reducing weaknesses.

1.3.1 Basic Principles of Solar-Wind Hybrid Power Plants

The basic principle of a solar-wind hybrid power plant is to integrate solar and wind power generation systems into one unified system. At certain times when one energy source is unavailable or insufficient, another energy source can take over, so that continuity of electricity supply can be maintained.

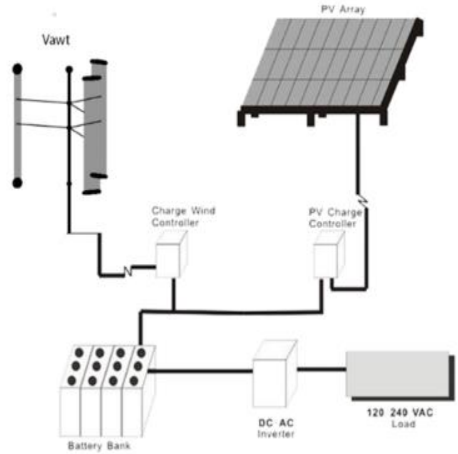

Figure 3. Hybrid Power Plant

1.3.2 Components in A Hybrid Power Plant

The following components are found in a hybrid power plant:

1. Solar Panels (Photovoltaics)

Solar panels consist of photovoltaic cells that convert direct sunlight into electricity through the photovoltaic effect. Solar energy received by solar panels is converted into direct current. [14]

Figure 4. Solar Panel

2. Wind Turbin

The wind turbine converts the kinetic energy of the wind into mechanical energy through the rotation of the propeller, then converted into electricity through a generator. Wind turbines usually produce direct current (DC) or alternating current (AC) depending on the type of generator used.[15]

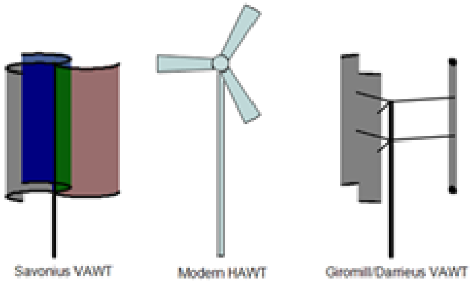

Figure 5. Wind Turbin

3. System Controller

The system controller is a component that regulates the distribution and storage of energy produced by solar panels and wind turbines. This controller ensures that the energy produced by both energy sources can be used efficiently and optimally. [16]

Figure 6. Solar Charge Controller

4. Storage Batteries

Storage batteries are used to store electrical energy produced by solar panels and wind turbines. This stored energy can be used when energy production from the main energy source is insufficient, such as at night or when the wind is not blowing. [17]

Figure 7. Battery

5. Inverter

Inverters convert direct current (DC) produced by solar panels and wind turbines into alternating current (AC) that can be used by household electrical appliances or fed into the power grid. [18]

Figure 8. Inverter

The solar and wind hybrid system represents one of the most promising approaches in achieving energy independence and environmental sustainability.[19] With advancing technology, this system is expected to become more efficient and affordable, and to serve as a key solution in the global transition towards renewable energy.[20]

This research will explore the concept of integrating solar and wind power, discussing the potential benefits offered, as well as the technical challenges that must be overcome to optimize the performance of this hybrid system.[5] The aim of this study is to identify solutions that can enhance efficiency, reliability, and cost savings in the use of renewable energy, while also supporting global efforts to reduce the environmental impact of conventional energy use.[21]

Methodology

In this research, the method used is direct experimentation and testing of the solar and wind hybrid system in the field. The aim is to measure the actual performance of the hybrid system under real environmental conditions. The steps in this method include design, installation, testing, as well as data collection and analysis. The stages of this method are explained as follows:

a. Literature Review and System Design: Before conducting experiments, a literature review is carried out to understand the basic concepts and designs of renewable energy hybrid systems. Based on the literature, the hybrid system combining solar and wind power is designed with the following considerations: a. Solar panel capacity suited to the solar radiation intensity at the location. b. Wind turbine specifications appropriate for local wind conditions. c. Energy storage system (battery) capable of storing the generated energy and distributing it when needed. d. Control system to manage the energy flow between the solar panels, wind turbines, battery, and loads.

b. Site Selection and Installation: The test site is selected based on the availability of renewable energy sources, i.e., a location with high solar energy potential and fairly stable wind speeds. The site selection is carried out by considering: a. Local weather data, including daily solar radiation intensity and wind speed, obtained from local meteorological stations or other reliable sources. b. Accessibility for equipment installation and maintenance. Once the site is determined, the hybrid system is installed at the location, which includes: c. Installing solar panels in an area exposed to direct sunlight. d. Installing wind turbines in an unobstructed area with optimal wind flow. e. Installing batteries for energy storage, as well as inverters and control systems for energy distribution.

c. System Performance Testing: Direct testing of the hybrid system is conducted over a certain period to observe its performance under varying weather conditions. This testing includes: a. Measuring energy production from solar panels and wind turbines separately and simultaneously. b. Monitoring energy storage in the batteries, including storage capacity and the efficiency of charging and discharging. c. Observing energy consumption from connected loads, such as lighting or household appliances, to assess the balance between energy production and consumption. The testing equipment used includes: d. Power meters to measure the electrical output of the solar panels and wind turbines. e. Weather sensors to measure solar radiation intensity, wind speed, temperature, and humidity.

d. Data Collection: Data collected during the testing period includes: a. Daily energy production from the solar panels and wind turbines. b. Battery charging and discharging levels, as well as charging times. c. Hybrid system performance under changing weather conditions (e.g., cloudy or windy conditions). d. Overall system efficiency, measured by the ratio of energy produced to energy consumed.

e. Data Analysis: After data collection, an analysis is conducted to evaluate the performance of the hybrid system under actual conditions. The analysis includes: a. Energy efficiency of the solar panels and wind turbines, including the comparison between energy generated and energy used. b. The effectiveness of the energy storage system in maintaining power supply during periods of low production. c. Performance comparison between using only one energy source (solar or wind) versus using both sources together (hybrid). d. The stability of the energy supply produced by the hybrid system.

f. Performance and Cost Evaluation: After data analysis, an evaluation is performed on the overall performance of the hybrid system and potential cost savings. This evaluation includes: a. The reliability of the hybrid system in consistently providing energy. b. Operational cost savings compared to using energy from conventional power grids. c. Carbon emission reductions from the use of renewable energy. d. Initial investment costs for the installation of solar panels, wind turbines, and batteries, as well as maintenance costs.

g. Conclusion and Recommendations: Based on the results of the experiments and direct testing, this research concludes the effectiveness of integrating solar and wind power in a hybrid system. Technical recommendations are also provided to improve the performance of the hybrid system in the future, such as: a. Optimizing the size and capacity of solar panels and wind turbines based on environmental conditions. b. Developing more efficient energy storage strategies. c. Adjusting the control system design to optimize energy distribution. In general, the research method or stages can be seen in the flowchart below:

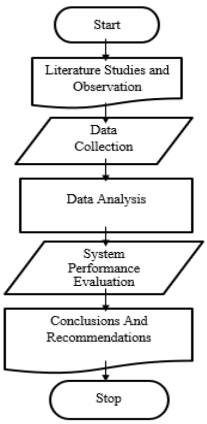

Figure 9. Flowchart

This method is expected to provide practical guidance for designing, testing, and implementing renewable energy hybrid systems that can be widely applied, especially in regions with high solar and wind energy potential.

Results

3.1 Desain Pembangkit listrik tenaga Hybrid

From the research carried out with the hybrid power generation system design as in Figure 10, the following results were obtained:

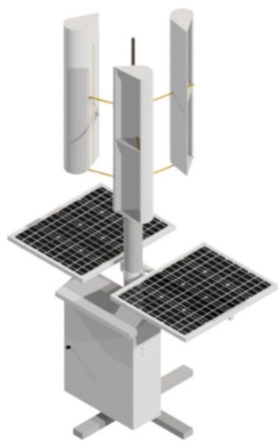

Figure 10. Hybrid Power Plant Design

3.1.1 Solar Irradiance Measurement

Measurement data can be seen in table 1.

Table 1. Solar Irradiance

Time	Solar Irradiance (W/m²)	Voltage (V)	Current (A)
10.40	97,128	18,90	0,59
10.50	110,033	19,72	0,59
11.00	110,055	19,78	0,58
11.10	109,916	19,26	0,56
11.20	109,938	11,27	0,56
11.30	109,888	19,13	0,55
11.40	109,994	19,52	0,57
11.50	109,944	19,40	0,51
12.00	110,094	19,80	0,58
12.10	100,096	19,86	0,58

From the data in the table above, the following graph is obtained:

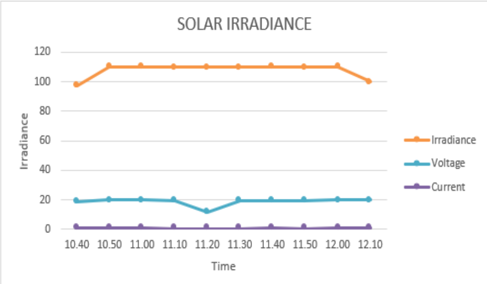

Figure 11. Solar Irradiance, Voltage and Current Graphs

From the table above, the average solar irradiance is: 107,7086 W/m2.

3.1.2 Wind Speed Measurement

The measured wind speed is as in table 2 below:

Table 2. Wind Speed

Suhu (ºC)	Kecepatan angin (m/s)	Tegangan (V)
33,4	1,1	1,02
33,4	1,2	1,07
33,3	1,3	1,18
33,3	1,4	1,28
33,3	1,6	1,47
33,2	1,7	1,62
33,2	1,8	1,69
33,2	1,9	1,71
33,2	2,0	1,78
33,1	2,2	1,84
33,1	2,3	1,89
33,1	2,6	2,03
33	2,8	2,05
33	3,9	3,20

from this table, the graph is:

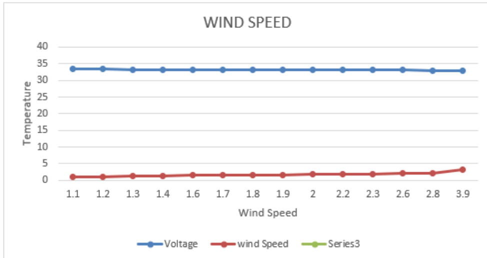

Figure 12. Wind speed, Voltage and Temperature Graphs

From table 2, the average wind speed is obtained 1,985 ≈ 2 m/s.

3.1.3 Input and Output Power on the Solar Panel Measurement

Next, based on the results of measuring the input and output power on the solar panel, the results obtained are as in the following table:

Table 3. Measurement of Input and Output Power on Solar Panels

Time	Irradiance (W/m^2)	P_{input} (W)	P_{output} (W)	π (%)
11.00	110,055	74,881	10,94	14
11.20	110,091	74,905	11,03	14
11.40	110,061	74,885	10,79	14
12.00	110,094	74,907	11,484	15
12.20	110,055	74,881	11,04	14
12.40	110,067	74,889	11,46	15
13.00	101,698	69,195	10,808	15
13.20	100,642	68,476	10,36	15
13.40	100,363	68,286	10,33	15
14.00	97,234	66,158	10,54	15
14.20	82,804	56,339	10,10	17
14.40	76,044	51,740	9,63	18
15.00	80,703	54,910	9,37	17

From the results of this measurement the average input power is: 68,035 watts, while the average output power is: 10,606 watts.

from this table, the graph is:

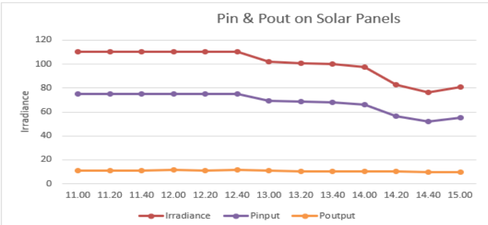

Figure 13. Graph of Input and Output Power on Solar Panels

3.1.4 Input and Output Power on Wind Turbines Measurement

The measurement of output power on wind turbines is listed in table 4.

Table 4. Measurement of Output Power on Wind Turbines

Time	Wind Speed (m/s)	Voltage (V)	P_{output} (W)
11.00	0,9	13,16	12,23
11.30	1,1	13,26	12,59
12.00	0,9	13,29	12,75
12.30	0,8	13,31	13,04
13.00	1,1	13,37	13,10
13.30	1,3	13,38	13,11
14.00	1,1	13,37	12,96
14.30	0,9	13,35	12,81
15.00	1,3	13,33	12,66
15.30	1,1	13,33	12,39
16.00	0,9	13,19	12,00

Based on the table above, the average output power is: 12,694 watts, with an average wind speed: 0.965 m/s. and the graph is:

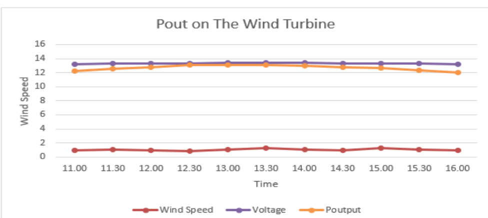

Figure 14. Graph of Output Power on The Wind Turbine

3.1.5 Efficiency Calculations

From the measurement data, the performance analysis of the hybrid generator can be calculated by adding up the output power of the two systems.

Poutput = Psun + Pwind
= 10,606 + 12,694
= 23,3 watt

Pinput = Psun + Pwind
= 68,035 + 0.9353
= 68,9703 watt

Then efficiency can be found with the equation:

$$\%\eta\text{hybrid} = \frac{Poutput}{Pinput} \times 100\%$$

$$\%\eta\text{hybrid} = \frac{23{,}3}{68{,}9703} \times 100\%$$

= 33,78 %

From the results above, it can be seen that the hybrid efficiency is greater than the efficiency of solar panels, so using a hybrid power plant is more efficient than using just one type of generator.

So the results obtained from this research are:

1. Technical Data Analysis

a. Energy Efficiency: The results of modeling and simulation indicate that the integration of solar and wind power increases energy efficiency compared to using each source separately. In varying weather conditions, the hybrid system is able to produce more stable energy output.

b. Energy Capacity and Production: This integration increases the total system capacity and annual energy production. Data shows that this combination can meet energy needs in remote areas more effectively than mono-energy systems.

2. Economic Data Analysis

a. Investment Costs: The initial investment costs for hybrid systems are higher compared to single-energy systems. However, cost-benefit analysis shows that in the long run, savings in operational and maintenance costs as well as reduced energy costs offset the initial investment costs.

b. Operational and Maintenance Costs: The hybrid system requires more complex maintenance but is more efficient in utilizing available energy resources.

3. Environmental Impact

a. Carbon Emissions Reduction: The integration of solar and wind power significantly reduces carbon emissions. Data shows that the hybrid system generates much lower emissions compared to fossil fuel power plants and is even more efficient than renewable mono-energy systems.

b. Impact on Local Ecosystems: No significant negative impact on local ecosystems was found from the operation of the hybrid system.

4. Case Study

a. Implementation in Remote Areas: Case studies in several remote areas show that the hybrid system is capable of providing a more reliable and stable electricity supply, overcoming challenges usually faced by conventional power grids in those regions.

b. Local Community Response: Interviews with local communities indicate positive support for the use of the hybrid system due to increased access to electricity and reduced dependence on fossil fuels.

3.2 Discussion

3.2.1 Integration Success

The success of solar and wind power integration highly depends on proper synchronization between the two energy sources, optimal system design, and the use of appropriate technology. Challenges such as variability in energy output can be overcome through efficient energy management and the use of energy storage technology. Although the initial investment costs are high, long-term benefits such as reduced operational and maintenance costs, as well as reduced carbon emissions, make the hybrid system an economically viable option in the long run. Government policy support and financial incentives can enhance the economic feasibility of this system.

3.2.2 Challenges and Solutions

The main challenges include the need for adequate infrastructure, energy distribution management, and dependence on weather conditions. Proposed solutions include the development of more efficient energy storage technology, the use of smart energy management systems, and improvements in distribution networks. Investment costs and economic uncertainty can be obstacles. Solutions include providing government incentives, reducing technology costs through economies of scale, and increasing public awareness and support.

3.2.3 Environmental Impact

The hybrid system significantly reduces carbon emissions, making it an environmentally friendly and sustainable solution. Additionally, the negative impact on local ecosystems is minimal, making it suitable for implementation in various environments. The integration of solar and wind power can enhance the stability of the electricity grid by providing a more reliable and consistent energy source, especially in remote areas.

3.2.4 Implementation in Remote Areas

The implementation of the hybrid system in remote areas not only improves access to electricity but also promotes local economic development and enhances the quality of life for the community. Active community involvement in the development and operation of the hybrid system is essential for the sustainability of the project and social acceptance.

With these results and discussions, it is expected that this research can make a significant contribution to the understanding and implementation of solar and wind power integration in renewable energy systems, as well as offer practical solutions to overcome existing challenges.

4. Conclusion

This study explores the potential and challenges of integrating solar and wind power into renewable energy systems. Based on the results of technical, economic, and environmental data analysis, as well as case studies conducted, the following conclusions can be drawn:

1. Increased Energy Efficiency: The integration of solar and wind power in a single hybrid system has been proven to significantly improve energy efficiency compared to the use of each energy source separately. The hybrid system is capable of producing more stable and reliable energy output, especially in varying weather conditions.

2. Integration Success: The success of integration largely depends on technical factors such as synchronization between the two energy sources, optimal system design, and efficient energy storage technology. Additionally, economic factors, such as high initial investment costs, can be offset by long-term savings in operational and maintenance costs.

3. Environmental Impact: The integration of solar and wind power significantly reduces carbon emissions, making it an environmentally friendly and sustainable solution. Moreover, this hybrid system has minimal impact on local ecosystems, making it suitable for implementation in various environments.

4. Challenges and Solutions: The main challenges in this integration include the need for adequate infrastructure, energy distribution management, and dependence on weather conditions. Proposed solutions include the development of more efficient energy storage technology, the use of smart energy management systems, and improvements in distribution networks. From an economic standpoint, government policy support and financial incentives can enhance the economic feasibility of this system.

5. Implementation in Remote Areas: The implementation of hybrid systems in remote areas shows that these systems are capable of providing a more reliable and stable electricity supply, overcoming challenges typically faced by conventional power grids in these regions. This not only improves access to electricity but also promotes local economic development and enhances the quality of life for the community.

6. Recommendations: Based on the research findings, it is recommended to continue developing and optimizing the technology for solar and wind power integration and to expand its application in various contexts and usage scales. The government and stakeholders need to provide policy support and incentives to encourage the adoption of these hybrid renewable energy systems.

With these conclusions, the research is expected to make a significant contribution to the understanding and implementation of solar and wind power integration in renewable energy systems, as well as offer practical solutions to overcome existing challenges in order to realize a more sustainable and environmentally friendly energy future.

Acknowledgment

On this occasion I would like to thank Universitas Pembangunan Panca Budi for providing the opportunity to conduct research, and especially thank to the Direktorat Riset, Teknologi, dan Pengabdian kepada Masyarakat, Direktorat Jenderal Pendidikan Tinggi Riset dan Teknologi, Kementerian Pendidikan, Kebudayaan, Riset dan Teknologi, which has provided fundamental research funds for the 2024 Fiscal Year.

WORKS CITED

A. Alsharif et al., "Hybrid Systems Renewable Energy Based Street Lighting Planning: A Case Study African" J. Adv. Pure Appl. Sci., vol. 1, no. 1, pp. 12-21, 2022. https://aaasjournals.com/index.php/ajapas/article/view/33

S. Anisah, “Analisis Sistem Pembangkit Listrik Tenaga Hybrid (Solar Cells & Wind Turbine) Untuk Kelistrikan Rumah Tinggal,” vol. 13, no. 2, pp. 203-207, 2024. DOI: https://doi.org/10.30591/polektro.v13i2.6698

SolarKita, “Hambatan Perkembangan Energi Baru Terbarukan Di Indonesia,” Kumparan.com, 2023. https://kumparan.com/solar-kita/hambatan-perkembangan-energi-baru-terbarukan-di-indonesia-20tlKtD9AeQ/full (accessed Mar. 20, 2024). https://kumparan.com/solar-kita/hambatan-perkembangan-energi-baru-terbarukan-di-indonesia-20tlKtD9AeQ/full

S. P. Mansur, “Analisis Pembangkit Hybrid Energi Terbarukan Dengan Metode Particle Swarm Optimization (PSO),” 2022. https://jurnal.poliupg.ac.id/index.php/sntei/article/view/3571

Agus Cahyono Adi, “Pemerintah Kejar Target Tingkatkan Bauran EBT,” Kementrian Energi dan Sumber Daya Mineral, 2024. (accessed Mar. 20, 2024). https://www.esdm.go.id/id/media-center/arsip-berita/pemerintah-kejar-tingkatkan-bauran-ebt

D. Ayu Kartika Sari, O. Sistem Pembangkit Listrik, F. Danang Wijaya, and H. Rois Ali, “Optimasi Sistem Pembangkit Listrik Tenaga Hybrid di Pulau Enggano,” 2022. https://journal.ugm.ac.id/v3/JNTETI/article/download/3849/1662

A. Suprajitno, S. B. Utomo, D. D. Nugroho, and J. T. Elektro, “CYCLOTRON : Jurnal Teknik Elektro Optimasi Sistem Pembangkit Listrik Tenaga Hybrid Energi Angin dan Surya Melalui Sistem Battery Charging Switching,” vol. 5. https://doi.org/10.30651/cl.v5i1.11281

G. Angga Setia, N. Winanti, F. Haz, and H. Rusiana Iskandar, “Desain Sistem Pembangkit Listrik Tenaga Hybrid (Solar Cell dan Wind Turbine) untuk Beban Perumahan,” 2021. https://epsilon.unjani.ac.id/index.php/epsilon/article/download/58/34

M. G. Fathurrachman, N. Busaeri, and N. Hiron, “Analisis Integrasi Pembangkit Listrik Hybrid Di Wilayah Daerah Pantai Tasikmalaya Selatan Menggunakan Aplikasi Homer,” 2022. DOI: https://doi.org/10.37058/jeee.v3i2.3744

R. Arindya, Energi Terbarukan, Pertama. Yogyakarta: TEKNOSAIN, 2018. https://balaiyanpus.jogjaprov.go.id/opac/detail-opac?id=309696

P. Roy, J. He, T. Zhao, and Y. V. Singh, “Recent Advances of Wind-Solar Hybrid Renewable Energy Systems for Power Generation: A Review,” IEEE Open J. Ind. Electron. Soc., vol. 3, no. December 2021, pp. 81–104, 2022, doi: 10.1109/OJIES.2022.3144093. https://doi.org/10.1109/OJIES.2022.3144093

Z. Tharo, E. Sutejo, and G. M. Sk, “Harnessing Solar Energy for Sustainable Urban Street Lighting,” vol. 1, no. 2, pp. 107–115, 2024. https://doi.org/10.69930/ajer.v1i2.149

B. Anjani et al., “Analisis penerapan tenaga bayu pada lampu pekarangan dengan turbin savonius 2024. https://doi.org/10.31539/intecoms.v7i4.11180

Z. Tharo, E. Syahputra, and R. Mulyadi, “Analysis of Saving Electrical Load Costs With a Hybrid Source of Pln-Plts 500 Wp,” J. Appl. Eng. Technol. Sci., vol. 4, no. 1, pp. 235–243, 2022, doi: 10.37385/jaets.v4i1.1024. https://doi.org/10.37385/jaets.v4i1.1024

J. P. Abraham, B. D. Plourde, G. S. Mowry, W. J. Minkowycz, and E. M. Sparrow, “Summary of Savonius wind turbine development and future applications for small-scale power generation,” J. Renew. Sustain. Energy, vol. 4, no. 4, 2012, doi: 10.1063/1.4747822. https://doi.org/10.1063/1.4747822

S. Anisah, R. Fitri, A. Kenedy Butar Butar, and Z. Tharo, “STUDY OF THE POTENTIAL OF NEW RENEWABLE ENERGY GENERATION (HIBRYD SOLAR AND WIND) AS AN ALTERNATIVE ENERGY SOURCE.” https://jurnal.pancabudi.ac.id/index.php/icesshi/article/view/4387

A. P. Putra, G. Rubiono, R. Nalandari, and M. G. Wardhana, “Design of Energy Education Media For Solar and Wind Power Plants at Bomo Beach, Banyuwangi Regency,” Log. J. Ranc. Bangun dan Teknol., vol. 23, no. 1, pp. 16–22, 2023, doi: 10.31940/logic.v23i1.16-22. https://doi.org/10.31940/logic.v23i1.16-22

M. Usman, “Analisis Intensitas Cahaya Terhadap Energi Listrik Yang Dihasilkan Panel Surya,” Power Elektron. J. Orang Elektro, vol. 9, no. 2, pp. 52–57, 2020, doi: 10.30591/polektro.v9i2.2047. https://doi.org/10.30591/polektro.v9i2.2047

F. HADIATNA, D. FAUZIAH, and E. SYAHIRAH, “Studi Kelayakan Pembangkit Listrik Tenaga Hybrid Surya Bayu di Kota Bandung,” ELKOMIKA J. Tek. Energi Elektr. Tek. Telekomun. Tek. Elektron., vol. 11, no. 3, p. 811, Jul. 2023, doi: 10.26760/elkomika.v11i3.811. https://doi.org/10.26760/elkomika.v11i3.811

S. J. Dewan, E. Nasional, and D. Siswanto, Bauran Energi Nasional 2020 Penanggung Jawab Peer Reviewer. https://den.go.id/publikasi/Bauran-Energi-Nasional

Z. A. S. R. F. Tharo, “Analisis Pembangkit Listrik Hybrid Surya-Bayu Untuk Pembelajaran Praktis,” vol. 8, no. 1, pp. 123–129, 2024, doi: 10.31289/jesce.v6i2.12522. DOI: 10.31289/jesce.v8i1.12522