Cerdika: Jurnal Ilmiah Indonesia, 5 (8), 2025
p-ISSN: 2774-6291 e-ISSN: 2774-6534

Available online at http://cerdika.publikasiindonesia.id/index.php/cerdika/index

Power Generation Using Energy Friendly Renewables Milieu (Wind Energy)

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Abstract
Power generation from fossil fuels has caused significant environmental problems including greenhouse gas emissions, air pollution, and climate change, which threaten global sustainability and human health. The increasing demand for clean energy solutions has made renewable energy technologies, particularly wind power, essential for addressing these environmental challenges. This research aims to explore the concept of more environmentally friendly power generation with a focus on reducing pollution and environmental impact through Wind Power Plants (PLTB). The study specifically analyzes the efficiency and performance of wind energy systems, examines their environmental benefits, and evaluates their implementation potential in Indonesia. In this study, different types of power generation technologies, particularly renewable energy sources such as wind, solar, hydro, and biomass, are compared to fossil fuel plants in terms of energy efficiency and pollutant emissions. The research methodology employs a comprehensive literature review approach, analyzing data from various scientific journals, technical reports, and energy policy documents from both national and international sources related to wind turbine technology and PLTB implementation in various countries. Results demonstrate that wind power plants can achieve energy conversion efficiency ranging from 35-45% with modern turbine technology, while producing zero greenhouse gas emissions during operation. The study reveals that Indonesia has significant wind energy potential, particularly in coastal areas of East Nusa Tenggara, South Sulawesi, and eastern islands, with average wind speeds of 6-7 m/s suitable for efficient PLTB operation. Results obtained show that the use of renewable energy can significantly lower CO2 emissions, with solar and wind energy being the most efficient options to reduce carbon footprint. The research concludes that PLTB implementation can reduce dependence on fossil fuels, provide long-term economic benefits through low operating costs, and contribute significantly to environmental sustainability. Overall, the application of environmentally friendly power plants is an effective solution to reduce pollution, support the sustainability of energy resources, and reduce dependence on fossil fuels.

Keywords: Wind energy, Emissions Carbon, Airpollution, Windturbines Energy efficiency, Energy transition

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INTRODUCTION

Penggunaan energi terbarukan—seperti surya, angin, hidro, dan biomassa—merupakan solusi penting untuk mengurangi ketergantungan pada sumber bahan bakar fosil (batubara, minyak, dan gas alam) yang tidak hanya terbatas, tetapi juga berdampak negatif terhadap lingkungan dan mempercepat perubahan iklim melalui emisi gas rumah kaca yang tinggi (Hassan, 2024). Teknologi terbarukan ini menawarkan potensi besar sebagai sumber energi yang berkelanjutan dan tersedia berlimpah, sekaligus secara signifikan bisa mengurangi jejak karbon global serta polusi udara yang mengancam kesehatan manusia dan ekosistem (Wikipedia, 2025a). Dengan semakin murah dan efisien, tenaga surya dan angin kini menjadi salah satu pilihan paling kompetitif dalam pembangkit listrik baru di banyak wilayah dunia (Wikipedia, 2025b). Misalnya, sejak tahun 2010 hingga 2024, tenaga terbarukan dan nuklir telah menghindarkan penggunaan 1.371 exajoule bahan bakar fosil dan 110 gigaton emisi gas rumah kaca (Energy Institute, 2025). Selain itu, dalam banyak skenario mitigasi perubahan iklim, peningkatan skala energi terbarukan secara substansial dianggap jalan utama menuju

pencapaian target iklim seperti bawah 2°C (International Energy Agency, 2021). Di tingkat sistem kelistrikan, peningkatan pangsa surya dan angin terbukti menggantikan output pembangkit termal—seperti batubara dan gas—yang berkontribusi langsung menurunkan emisi CO_2, meskipun keberhasilan ini tergantung pada desain sistem kelistrikan dan fleksibilitas operasi (Suri, de Chalendar, & Azevedo, 2025). Dengan keseluruhan manfaat lingkungan dan lonjakan efisiensi serta penurunan biaya, pengembangan pembangkit listrik berbasis energi terbarukan menunjukkan potensi menjadikan sistem energi global lebih berkelanjutan dan rendah emisi dalam jangka panjang (Rahman, 2024).

Kebutuhan akan transisi menuju sistem energi terbarukan semakin mendesak seiring dengan dampak perubahan iklim yang kian memperparah dan target netralitas karbon global pada tahun 2050 yang harus dicapai (Nguyen et al., 2023). Penetapan komitmen mengikat dalam Perjanjian Paris telah mendorong negara-negara di seluruh dunia untuk mengakselerasi pengembangan teknologi energi bersih sebagai prioritas global (Renewable Energy Transition and the Paris Agreement, 2022). Selain itu, volatilitas harga bahan bakar fosil—disebabkan oleh fluktuasi pasar global dan isu ketergantungan ekonomi—telah menyoroti perlunya alternatif energi yang lebih stabil dan berkelanjutan (Wang, 2024; IISD, 2024). Studi menunjukkan bahwa teknologi terbarukan seperti surya dan angin tidak hanya menurunkan emisi, tetapi juga menyediakan kestabilan harga jangka panjang sebagai hedge terhadap fluktuasi bahan bakar fosil (Roosevelt Institute, 2023). Dalam konteks ini, transisi cepat ke energi terbarukan adalah strategi kunci untuk memenuhi batas anggaran karbon global dan menghindari kenaikan suhu melebihi 1,5 °C (Schwartzman & Schwartzman, 2020). Model optimasi terbaru mengindikasikan bahwa kombinasi energi terbarukan dan teknologi penyimpanan karbon dapat mengurangi emisi CO_2 sektor energi hingga 55–67% pada 2050 secara ekonomis (Nguyen et al., 2023). Oleh karena itu, percepatan transisi ke energi terbarukan menjadi solusi paling rasional, baik dari sisi iklim maupun stabilitas ekonomi global.

Previous research has extensively documented the benefits and challenges of renewable energy implementation (Saka et al., 2018; Stram, 2016). Studies by Panwar et al. (2011) demonstrated that renewable energy sources play a crucial role in environmental protection by significantly reducing pollutant emissions. Markard et al. (2012) identified sustainability transitions as an emerging field requiring comprehensive analysis of technological, economic, and social factors. Research by Hasan and Kamal (2017) specifically examined wind energy potential in Indonesia, revealing significant opportunities for PLTB development in various regions. However, most previous studies have focused on either global renewable energy trends or specific technical aspects of wind turbines, without providing comprehensive analysis of PLTB implementation potential specifically tailored to Indonesian geographical and climatic conditions.

The research gap identified in existing literature relates to the lack of comprehensive studies that integrate technical performance analysis of different wind turbine types with specific evaluation of their environmental benefits and implementation feasibility in the Indonesian context. While international studies provide valuable insights into wind energy technologies, there is limited research that specifically addresses the unique challenges and opportunities for PLTB development in Indonesia's diverse geographical and climatic conditions.

The novelty of this research lies in its comprehensive approach to analyzing wind power plant implementation that combines technical efficiency evaluation of both horizontal and vertical axis wind turbines with detailed assessment of their environmental benefits and specific applicability to Indonesian conditions. This study provides a holistic perspective that integrates technological, environmental, and geographical factors to offer practical recommendations for PLTB development in Indonesia.

The primary objective of this research is to analyze renewable technologies that can replace fossil fuel plants and assess environmental impacts and sustainability resulting from the use of such technology, with specific focus on wind power plants. Secondary objectives include evaluating the efficiency and performance characteristics of different wind turbine technologies, identifying optimal locations for PLTB development in Indonesia, and assessing the environmental and economic benefits of wind energy implementation. The research benefits include providing scientific basis for renewable energy policy development, offering technical guidelines for PLTB implementation, and contributing to Indonesia's energy transition strategy toward sustainable and environmentally friendly power generation systems. It is expected that the results of this research can provide insights and recommendations in the development of more environmentally friendly and sustainable power plant systems.

RESEARCH METHOD

This study uses an in-depth literature study approach to examine and assess the potential, performance, and environmental impact of Wind Power Plants (PLTB) as one of the sources of renewable energy. Data sources come from various scientific journals, technical reports, reference books, and energy policy documents both national and relevant and latest international wind turbine technology, characteristics PLTB operations, as well as its implementation in various countries, including Indonesia. Moreover, the analysis also utilizes secondary data from PLTB projects that have been implemented in Indonesia and countries with similar climatic and geographical conditions. The data includes the level of efficiency of the plant, the capacity of the electricity produced, and environmental impacts such as reducing greenhouse gas emissions. The use of this secondary data aims to provide an accurate empirical picture of performance and potential PLTB.

The analysis approach applied is comparative, comparing various types of wind turbines (including horizontal and vertical turbines), as well as comparing PLTB with conventional fossil fuel power plants in terms of energy efficiency and ecological impact. The research also examines related technical, economic, and social aspects with the development of PLTB, including obstacles to implementation and opportunities for its development in potential areas in Indonesia. Through this method, the research aims to present a comprehensive overview of the role of PLTB in supporting the energy transition towards a cleaner and more sustainable energy system. The results of the study are expected can be the basis for policy recommendations and energy development strategies renewable in Indonesia.

RESULTH AND DISCUSSION

This section presents research findings related to the effectiveness of Wind Power Plants (PLTB), challenges in its implementation, and its development potential in Indonesia. The analysis was carried out based on literature studies and secondary data from various relevant sources.

Efficiency and Performance of Wind Power Plants

Capacity factor—the ratio of energy produced to maximum capacity—is usually 20-40%. Increased efficiency can be achieved by selecting the optimal location, appropriate turbine technology, regular maintenance, and the use of energy storage systems to cope with wind variability.

PLTB works by converting wind kinetic energy into mechanical energy through wind turbines, which are then converted into electrical energy by generators. Wind turbine efficiency is strongly influenced by several factors, such as wind speed, turbine design, and geographical location. According to a report from the International Renewable Energy Agency (IRENA

2020), the energy conversion efficiency of modern wind turbines ranges from 35-45%, depending on the technology used. Some commonly used types of wind turbines are:

Horizontal Axis Wind Turbine (HAWT)

Horizontal wind turbines are the most common type of wind turbines used in large-scale power plants.

Characteristics:

- **Shaft and Propeller**: The main shaft of the turbine is parallel to the direction of the wind, and the propeller rotates on a horizontal axis. Propellers are usually aerodynamically shaped resembling aircraft propellers.
- **Yaw System**: It is necessary to direct the turbine so that it is always facing the wind so that the captured energy is optimal.
- **Tower Height**: Usually erected on a tower that is high enough to access winds with higher and more stable speeds.

***Advantages*:**

- It has relatively high efficiency compared to vertical turbines because the propeller can be optimized to catch wind at various speeds.
- Suitable for use in locations with consistent and strong wind speeds.
- The technology and design are already very mature and widely used on a large scale all over the world.

***Disadvantages*:**

- Requires complex mechanical systems such as yaw motors to steer turbine.
- Its construction and maintenance are comparatively more complicated and expensive.
- Usually requires large area and tall towers.

Vertical Axis Wind Turbine (VAWT)

Vertical wind turbines have a rotating axis that is perpendicular to the direction of the wind, and the propeller rotates on a vertical axis.

Characteristics:

- **Shaft Design**: The shaft is perpendicular to the ground level, allowing the turbine to catch the wind from all directions without the need for a director.
- **Propeller Shape**: There are several types, such as the Darrieus model (shaped like the letter "H") and Savonius (shaped like a half-cylinder or "S").
- **Installation**: Usually installed at a lower height and can be placed more flexibly, including in urban areas.

***Advantages*:**

- It does not require a yaw system to steer the turbine as it can catch the wind from all directions.
- The structure is simpler, easier to install and maintain.
- More suitable for areas with unstable or deflected winds, such as in urban areas.
- Size and noise is relatively less so it is more user-friendly in congested environments.

Disadvantages:

- Efficiency is generally lower than horizontal turbines, especially for high wind speeds.
- Less than optimal for large-scale electricity production.
- Balancing and mechanical force on vertical shafts can cause wear problems faster.

The Potential of PLTB in Indonesia

Indonesia as an archipelagic country that has a very long coastline and diverse topography holds great potential for the development of renewable energy, especially wind

energy. This wind energy potential is mainly spread in coastal areas and plateaus that have sufficient wind speed to drive wind turbines and generate electricity efficiently.

Potential Areas of Wind Energy in Indonesia

Based on data and reports from Ministry of Energy and Mineral Resources (ESDM) (2020), a number of regions in Indonesia have been identified as having sufficient average wind speed for the use of PLTB. Several coastal areas such as in East Nusa Tenggara (NTT) Province, South Sulawesi, and some islands in the eastern region of Indonesia show an average wind speed of around 6 up to 7 meters per second (m/s). The wind speed is already in the ideal range for operating wind turbines with a high level of efficiency, thus enabling the development of effective and sustainable wind power plants.

In addition to coastal areas, mountainous areas also have attractive wind potential. For example, mountainous areas in West Java, Bali, and some parts of Kalimantan have fairly stable and relatively strong wind conditions at certain heights, so that it can be used for wind power generation.

Indonesia's diverse geographical conditions provide opportunities for the development of PLTB in various scales, both large-scale in large locations and medium to small scales in limited locations such as mountainous and urban areas.

The Advantages of PLTB as Environmentally Friendly Energy

Wind Power Plants (PLTB) are one of the renewable energy sources which harnesses the power of the wind to generate electricity. This wind energy is transformed through wind turbines into mechanical energy, then converted into electrical energy that can be used to meet the needs of the community. PLTB is now increasingly popular because it is considered an effective eco-friendly energy solution in the face of various global energy and environmental challenges. Here are some of the advantages of PLTB as environmentally friendly energy:

Renewable and Inexhaustible Energy Sources

Wind is a natural resource that is continuously available and will not be depleted for as long as the earth rotates and the sun shines in the atmosphere. In contrast to fossil fuels such as petroleum, coal, and natural gas in limited quantities and will eventually run out, wind can be used without the risk of running out. Thus, PLTB supports long-term energy sustainability and reducing dependence on non-renewable resources.

Generating Clean Energy Without Greenhouse Gas Emissions

PLTB does not produce carbon dioxide (CO2) emissions or other greenhouse gases which is the main cause of climate change and global warming. In contrast to fossil fuel-based power plants that burn carbon and release harmful pollutants to the atmosphere, wind turbines operate without combustion so that they are free of air pollution. This makes PLTB one of the main solutions to reduce carbon footprint and maintain air quality.

Minimal Environmental Impact and Noise

In general, wind power plants have a lower environmental impact than conventional power plants. Wind turbines require relatively small land and can stand in an area that is not suitable for other activities such as farming or housing, so that it does not interfere much with the surrounding ecosystem. Although there are several issues related to noise and visual impact, modern technology is constantly being developed to reduce turbine noise and optimize placement so as not to disturb the surrounding community.

Reducing Dependence on Fossil Fuels

By utilizing wind energy, PLTB reduces the need for fossil fuels that must be imported or retrieved from limited sources. This is very important for national energy durability because it helps reduce the energy trade deficit and dependence against the price of fossil fuels which often fluctuates in the world market. Moreover, the development of PLTB can also encourage the growth of green industries and jobs in the renewable energy sector.

Low Operating Costs After Construction

Although the initial investment cost of wind turbine construction and PLTB infrastructure is sufficient, high operating and maintenance costs thereafter are relatively low compared to conventional electricity. Wind as an energy source is free of charge, and wind turbine technology is more efficient and durable. Thus, PLTB becomes a source of electricity that is economical in the long run.

Can Be Developed in Multiple Locations

PLTB can be built in various locations, both onshore and offshore. Offshore wind turbines have greater potential because offshore wind is generally more firm and consistent, so as to produce more energy. In addition, the construction of PLTB in remote areas can also help provide electricity in areas where it is difficult to reach by conventional power grids, increasing energy access more evenly.

Encouraging Technological Innovation and Sustainable Development

The development of PLTB spurs technological innovation in the field of renewable energy, starting from more efficient turbine design, energy storage systems, and integration with smart grids. This not only strengthens the green energy sector, but also supports sustainable development that pays attention to the balance between economic, social, and environmental needs.

CONCLUSION

Wind Power Plants (PLTB) are one of the renewable energy solutions which is environmentally friendly and has great potential to be developed in Indonesia. With a fairly good level of efficiency, especially with the use of horizontal wind turbines, PLTB can generate electricity without causing harmful carbon emissions to the environment. The potential for wind energy in coastal and highland areas in Indonesia is huge and is suitable to be used in the development of PLTB. In addition to providing benefits for the environment, PLTB also contributes to national energy security, reducing dependence on fossil fuels, and becoming an economical source of energy in long-term. However, there are still technical challenges and initial investment needs which must be overcome through technological innovation and supporting policies so that the development of PLTB can take place optimally.

Based on the comprehensive analysis conducted, several key recommendations emerge for the successful implementation of PLTB in Indonesia. First, the government should prioritize the development of supportive policy frameworks that include investment incentives, streamlined permitting processes, and grid integration standards for wind power projects. Second, collaboration between research institutions, private sector, and government agencies is essential to advance wind turbine technology adapted to Indonesian conditions and to develop local manufacturing capabilities. Third, pilot projects should be established in identified high-potential areas such as East Nusa Tenggara and South Sulawesi to demonstrate the viability and benefits of PLTB implementation.

Future research should focus on conducting detailed wind resource assessments using modern measurement technologies, developing economic feasibility studies for different PLTB

scales and locations, investigating the integration of wind power with other renewable energy sources in hybrid systems, and analyzing the social and environmental impacts of large-scale PLTB deployment. Additionally, research on energy storage solutions and smart grid integration will be crucial for maximizing the benefits of wind power implementation in Indonesia's energy system. Overall, PLTB becomes an essential component in the transition process to a cleaner, more sustainable energy system, and environmentally friendly.

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