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A Performance Comparison Analysis of Solar Power Plants and Steam Power Plants in the Context of PT Rapp

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ABSTRACT
The growing emphasis on renewable energy and environmental sustainability has driven industries to explore cleaner energy sources. This study focuses on compairing the performance of Solar Power Plants(SPPs) and Steam Power Plants(SPPs) operated by PT Riau Andalan Pulp and Paper(PT RAPP) in Riau, Indonesia. The research utilized daily energy production records, environmental observations, and statistical analysis to assess the efficiency, reability, and sustainability of both systems. Results indicate thet Solar Power Plants are highly efficient in converting solar radiation into electricity but face operational challenges due to equipment malfunction, particularly in Phases On the other hand, Dual Fuel Line 2 Steam Power Plant demonstrated consistent performance, achieving a thermal efficiency of 43.24% by utilizing biomass as a primary fuel. Despite this, it still requires natural gas for operational stability. The study concludes with recommendations for enhancing solar power plant maintenance, expanding capacity, and investing in emission control technologies for steam plants. These steps aim to create a more sustainable and efficient energy ecosystem for PT RAPP, supporting its long-term energy needs and environmental goals.

Keywords : ***Solar Power Plant, Steam Power Plant, Renewable Energy and Sustainability***

INTRODUCTION

Energy sustainability has become a critical concern worldwide, with industries increasingly adopting renewable energy systems to mitigate climate change and reduce dependency on fossil fuels. Solar Power Plants (SPPs) represent a key innovation in this transition, utilizing photovoltaic (PV) technology to convert sunlight into electricity. This is particularly relevant in tropical regions like Indonesia, where high solar radiation levels - averaging 4.5 kWh per day-offer significant potential for solar energy deployment.PT Riau Andalan Pulp and Paper (PT RAPP), a leading player in the pulp and paper industry, has embraced this renewable energy transition. The company operates bothWhile SPPs are lauded for their environmental benefits, their performance is highly weather-dependent. Conversely, Steam Power Plants, which primarily use biomass and natural gas, provide a more stable energy output but pose environmental challenges due to emissions.

This study aims to analyze and compare the operational efficiency, environmental impact, and cost-effectiveness of these two energy systems. By understanding their strengths and limitations, PT RAPP can optimize its energy strategies, aligning operational goals with sustainability targets. Energy plays a crucial role in industrial operations, directly influencing production efficiency, operational costs, and environmental sustainability. PT Riau Andalan Pulp & Paper (PT RAPP), a major player in the pulp and paper industry, relies on a stable and

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efficient power supply to support its large-scale manufacturing processes. Given the increasing global focus on renewable energy and sustainability, the company is exploring alternative energy sources, particularly solar power plants (SPP), as a potential supplement or replacement for conventional steam power plants (SPP) that primarily rely on fossil fuels.

This study aims to provide a comparative performance analysis between solar power plants and steam power plants in the context of PT RAPP. The comparison will be based on key performance indicators, including:

- Energy efficiency → Measuring energy conversion rates and overall plant efficiency.
- Operational costs → Analyzing capital expenditure (CAPEX), operational expenditure (OPEX), and long-term cost benefits.
- Environmental impact → Evaluating carbon emissions and sustainability factors.
- Reliability and availability → Assessing power stability and potential downtime risks.

By conducting this analysis, we seek to determine whether solar power can effectively complement or replace steam power generation at PT RAPP, considering both economic and environmental perspectives. The findings will contribute to strategic decision-making in the company's energy management and long-term sustainability goals.

LITERATURE REVIEW

Solar Power Plants (SPP)

Solar power plants utilize photovoltaic (PV) panels or concentrated solar power (CSP) systems to convert sunlight into electricity. PV systems directly convert solar energy into electrical power using semiconductor materials, while CSP systems use mirrors to focus sunlight, generating heat to drive a steam turbine. Several studies highlight the advantages of solar power, including:

- Renewable and abundant energy source (International Energy Agency, 2022).
- Minimal greenhouse gas emissions compared to fossil fuel-based power plants (Dincer & Acar, 2015).
- Low operating and maintenance costs due to the absence of fuel consumption (Chowdhury et al., 2020).
- Intermittency and efficiency challenges depending on geographic location and weather conditions (Kalogirou, 2013).

Steam Power Plants (STPP)

Steam power plants operate based on the Rankine cycle, where fossil fuels such as coal, oil, or natural gas are burned to generate steam, which then drives a turbine to produce electricity. Key characteristics of steam power plants include:

- High reliability and consistent power output (Boyce, 2017).
- Scalability for industrial and base-load power applications (Breeze, 2014).
- Significant carbon emissions and environmental impact (IPCC, 2021).
- High operational and fuel costs due to dependence on non-renewable resources (Chattopadhyay, 2019).

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Energy Efficiency

- The efficiency of solar PV systems typically ranges from 15% to 22%, while CSP systems can achieve up to 40% efficiency under optimal conditions (Green et al., 2020).
- Steam power plants, depending on fuel type and technology, generally operate with an efficiency range of 30% to 45% (Rosen et al., 2018).
- Capital Expenditure (CAPEX): Solar power plants require high initial investment for PV modules, inverters, and land acquisition, but have low operational costs (IRENA, 2021).
- Operating Expenditure (OPEX): Steam power plants involve ongoing costs for fuel, maintenance, and emission control systems (Singh et al., 2016).
- Levelized Cost of Electricity (LCOE): Solar power has experienced a significant reduction in LCOE, making it more cost-competitive compared to fossil fuel-based power (Lazard, 2022).
- Carbon footprint: Steam power plants contribute significantly to CO_2 emissions, whereas solar power plants produce near-zero emissions (Sharma et al., 2021).
- Land and water use: CSP systems require large land areas and some water for cooling, while PV systems require minimal water compared to steam power plants, which have high water consumption for cooling processes (Mekhilef et al., 2012).
- Solar power generation depends on sunlight availability, leading to intermittency issues that require energy storage or grid balancing solutions (Kumar & Majid, 2020).
- Steam power plants provide stable, continuous electricity generation, making them suitable for base-load applications (Gupta & Choudhary, 2018).
- Several researchers have conducted comparative analyses of solar and steam power plants:
- Hossain et al. (2020) compared solar PV and coal-fired steam power plants, concluding that solar is more sustainable but requires storage solutions.
- Patel et al. (2019) analyzed CSP vs. conventional power plants, highlighting the need for hybrid solutions.
- Zhao et al. (2021) studied the economic feasibility of replacing coal power with solar energy in industrial applications, showing significant cost savings over time.
- While extensive research exists on solar and steam power plants, limited studies focus on their comparative performance in industrial settings like PT RAPP. This study fills the gap by:
- Analyzing real-world performance data for both power plants at PT RAPP.
- Considering economic, technical, and environmental factors specific to the pulp and paper industry.
- Providing recommendations on optimal energy mix for sustainable and cost-effective power generation.

METHODS

The study employs a descriptive research approach, focusing on evaluating the performance metrics of Solar Power Plants (SPPs) and Steam Power Plants (SPPs). Key aspects such as energy efficiency, reliability, operational costs, and environmental impact were assessed using quantitative data and qualitative insights. PT RAPP operates in Riau, Indonesia, a region with abundant solar radiation and significant industrial activity. This setting provides a unique

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opportunity to explore the feasibility of integrating renewable energy systems in large-scale industrial operations. Solar Power Plants: Data included daily energy output, module efficiency, and inverter performance across four phases of installation. Steam Power Plants: Records included thermal efficiency, fuel usage (biomass and natural gas), and energy output stability. Weather patterns, solar radiation intensity, and emission levels were monitored to assess their impact on energy systems. Operational staff provided insights into technical challenges, maintenance practices, and system reliability.

Secondary data from industry reports and academic studies were used to contextualize findings and validate performance benchmarks. The collected data were analyzed using statistical methods to calculate efficiency rates, cost- effectiveness, and emission reduction potentials. Comparative metrics were developed to highlight the advantages and limitations of each system, guiding recommendations for improvement.

RESULTS AND DISCUSSION

Results

Solar Power Plants (SPPs) Performance

PT RAPP's Solar Power Plant (SPP) initiative is divided into four phases, each reflecting different capacities and technical setups. These installations aim to capitalize on Riau's abundant solar radiation to produce clean energy while reducing reliance on fossil fuels.

Phase 1 and 2 Overview

Phase 1: With an installed capacity of 1 MW using 2,966 photovoltaic (PV) modules and 10 inverters, this phase demonstrated high efficiency and reliability.

Phase 2: Expanded capacity to 10 MW, utilizing 19,474 PV modules and 40 Inverters. This phase successfully scaled operations, maintaining performance metrics close to expectations. Despite initial successes, Phase 3 faced significant setbacks due to technical issues. A total of 1,659 PV modules were reported non-functional, while four of the 72 inverters experienced failures. These issues led to a significant production drop, with actual energy output at 27.54 MWh compared to the target of 72 MWh.

Environmental Benefits

SPPs at PT RAPP have made notable contributions to environmental sustainability. Solar energy generation produces zero greenhouse gas emissions during operation, aligning with the company's long-term goals of reducing its carbon footprint by 25% by 2030. The operational cost of SPPs remains low compared to conventional power systems, primarily due to the absence of fuel costs. However, the efficiency of these systems heavily depends on regular maintenance and technological upgrades to address equipment failures and optimize performance. Steam Power Plants (SPPs) Performance The Dual Fuel Line 2 Steam Power Plant at PT RAPP is a high-capacity facility utilizing biomass as its primary fuel source, supplemented by natural gas. This combination supports stable energy production while reducing reliance on non-renewable resources. The plant achieved a thermal efficiency of 43.24%, a commendable figure for a biomass- based system. This efficiency was calculated based on the energy conversion ratio from input fuel to usable electricity, factoring in energy losses through heat dissipation and operational processes.

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Emission Reductions

Using biomass such as wood bark, palm kernel shells, and other agricultural residues, the plant significantly reduces greenhouse gas emissions compared to coal-fired alternatives. However, natural gas supplementation remains necessary to maintain operational stability, particularly during periods of high energy demand. While biomass Is more sustainable than coal, its procurement and processing involve logistical complexities that increase operational costs. Despite this, the consistent energy output and reduced environmental impact position the Steam Power Plant as a reliable energy source for PT RAPP.

Table 1. Comparison of Key Performance Metrics

Criteria	Solar Power Plants	Steam Power Plants
Efficiency	High (Phase 1-2) moderate (phase 3)	Stable (43.24%)
Environmental impact	Zero emissions	Reduced emissisons(biomass based)
Operational cost	Low	Moderate to high
Stability	Weather-dependent	Rellable, 24/7 operation
Investmen cost	High (due to PV technology)	High (infrastructure-focused)

Key Insights Complementary Roles

Solar Power Plants excel in sustainability and cost-efficiency, making them ideal for long-term environmental goals. Conversely, Steam Power Plants provide stability and high output, ensuring operational continuity regardless of weather conditions. The malfunctions in Phase 3 of the Solar Power Plant project underscore the importance of robust maintenance protocols and regular system evaluations. Both systems exhibit potential for expansion. However, scaling Solar Power Plants requires addressing land use concerns and improving equipment reliability, while Steam Power Plants demand further investment in emission control technologies.

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Solar Power Plant Enhancements

Equipment Upgrades: Replace outdated or malfunctioning PV modules and inverters to enhance system reliability and efficiency. Monitoring Systems: Invest in advanced monitoring tools to track real-time performance and detect potential failures early. Phase Expansion:

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Accelerate the implementation of Phase 4 and explore additional rooftop installations to maximize solar energy utilization. Emission Control: Introduce advanced emission reduction technologies, such as carbon capture systems, to further mitigate environmental impact. Fuel Optimization: Increase biomass usage and reduce reliance on natural gas by improving fuel supply chains and exploring alternative renewable fuels. Hybrid Systems: Develop hybrid energy solutions that integrate solar and steam power plants, ensuring a balance between stability and sustainability. Energy Storage: Implement large-scale battery storage systems for Solar Power Plants to address weather-dependent fluctuations. Data-Driven Decision-Making: Use predictive analytics and historical data to optimize energy production and allocate resources efficiently.

Collaborate with local and national stakeholders to align energy projects with broader sustainability initiatives. Educate the community on the benefits of renewable energy to foster support To build upon the findings of this study, future research could focus on: Long-term cost-benefit analyses of hybrid energy systems. The environmental and social impact of large-scale renewable energy adoption. Technological innovations to improve the scalability and efficiency of both Solar and Steam Power Plants.

CONCLUSION

This study highlights the comparative performance of Solar Power Plants (SPPs) and Steam Power Plants (SPPs) within PT RAPP's energy ecosystem. Solar Power Plants demonstrated remarkable environmental benefits, including zero emissions and low operational costs. However, their efficiency is significantly affected by equipment reliability and weather conditions. The challenges faced in Phase 3, particularly with non- functional PV modules and inverter failures, underscore the importance of robust maintenance and monitoring systems. Conversely, the Steam Power Plant's consistent energy output and thermal efficiency of 43.24% reflect its reliability and capacity to meet large-scale energy demands. By utilizing biomass as a primary fuel, this system contributes to emission reductions, though natural gas dependency for operational stability presents a challenge to sustainability goals. Both energy systems play vital roles in PT RAPP's strategy to balance operational efficiency with environmental responsibility. The combination of these systems offers a practical approach to meeting energy demands while advancing toward renewable energy goals.

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