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Optimizing Maintenance Budgets and LED Investment to Improve Power Plant Reliability and Sustainability

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ABSTRACT

Objectives: Power plant reliability and sustainability are critical factors in ensuring a stable electricity supply. PLTU Suralaya Units 5–7, one of the largest coal-fired power plants in Indonesia’s Java–Bali system, has experienced increasing operational disturbances and rising maintenance costs due to suboptimal budget allocation. This study aims to analyze strategies to enhance power plant reliability and sustainability through maintenance budget optimization and investment in LED lighting technology.

Methodology: This research employs a mixed-method case study approach integrating qualitative and quantitative analyses. Data were obtained from operational reports, maintenance budget records, disturbance logs, and field observations. Analytical tools include SWOT analysis, IFE–EFE matrices, and time series analysis to evaluate performance before and after optimization implementation.

Finding: The results indicate that maintenance budget optimization based on asset criticality improves preventive maintenance effectiveness, reduces forced outages, and enhances reliability performance. Additionally, LED lighting investment reduces internal energy consumption, lowers operational costs, and minimizes hazardous waste from conventional lighting systems.

Conclusion: This study concludes that integrating maintenance budget optimization with LED investment effectively improves reliability, cost efficiency, and sustainability performance. The findings provide a practical managerial framework for power plant operators seeking to enhance operational performance while supporting sustainability objectives.

Keywords: Reliability; Sustainability; Maintenance Budget Optimization; Power Plant; LED Investment.

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INTRODUCTION

Reliable and sustainable electricity supply is a fundamental prerequisite for economic growth, industrial development, and national energy security. In developing countries such as Indonesia, electricity demand continues to increase in line with population growth, urbanization, and industrial expansion (IEA, 2023; Chien, 2022). The Java–Bali power system, which accounts for the largest share of national electricity consumption, relies heavily on coal-fired power plants (PLTU) as baseload generators due to their stable output and cost competitiveness (IEA, 2023).

PLTU Suralaya Units 5–7, operated by PT PLN Indonesia Power, represent one of the largest coal-fired power plants in the Java–Bali system and play a strategic role in maintaining system reliability. In recent years, however, the plant has faced increasing operational challenges, including a higher frequency of forced outages, declining availability factors, and rising maintenance costs. These conditions directly affect reliability indicators such as the Equivalent Availability Factor (EAF) and Equivalent Forced Outage Rate (EFOR), which are critical parameters in evaluating power plant performance (Siswanti et al., 2024).

One of the major contributing factors to these challenges is the allocation of maintenance budgets that has not been fully optimized based on asset criticality and operational risk. Traditional maintenance budgeting practices often rely on historical expenditure patterns rather than systematic risk-based or performance-based approaches. As a result, critical assets may receive insufficient maintenance attention, while non-critical components consume a disproportionate share of the budget. This misallocation increases the likelihood of equipment failure, reduces operational reliability, and ultimately raises total lifecycle costs (Nguyen, 2024; Zhang, 2024).

In parallel, power plant operators face increasing pressure to implement sustainability principles and improve energy efficiency in response to global environmental concerns and national policy commitments. Indonesia has committed to reducing greenhouse gas emissions and supporting the achievement of the Sustainable Development Goals (SDGs), which emphasize responsible energy production and consumption. Within power plant operations, sustainability extends beyond emission reduction to include efficient internal energy use, waste reduction, and environmentally responsible asset management (Chien, 2022).

One practical and often overlooked area of energy efficiency within power plants is the lighting system. Conventional lighting technologies consume significant amounts of internal energy and generate hazardous waste, particularly mercury-containing lamps. The adoption of light-emitting diode (LED) technology offers substantial advantages, including lower energy consumption, longer service life, reduced maintenance requirements, and minimized environmental impact. Therefore, investment in LED lighting can simultaneously contribute to cost efficiency and sustainability objectives (Pizzichetti et al., 2024).

Despite extensive studies on maintenance optimization and energy efficiency in power plant operations, most prior research treats these initiatives as separate managerial efforts. Empirical studies integrating maintenance budget optimization with sustainability-oriented investments, particularly in large-scale coal-fired power plants, remain limited. Moreover, there is a lack of case-based evidence demonstrating how efficiency gains from maintenance budget optimization can be strategically reallocated to support sustainability initiatives (Prabowo et al., 2025).

The novelty of this study lies in its integrated managerial approach, which connects reliability improvement and sustainability enhancement through a single financial optimization framework. By reallocating efficiency gains from maintenance budget optimization into energy-efficient LED investment, this research proposes a practical pathway for power plant operators to achieve operational reliability and sustainability simultaneously. This integrated perspective extends existing literature by providing empirical evidence from a real-world large-scale power plant.

Accordingly, this study aims to analyze how maintenance budget optimization and LED lighting investment can strengthen power plant reliability and sustainability at PLTU Suralaya Units 5–7. By employing a mixed-methods case study approach, this research seeks to provide empirical evidence and managerial insights that can serve as a reference for power plant operators in improving operational performance in a sustainable manner.

LITERATURE REVIEW

Reliability of Power Plants

Power plant reliability refers to the ability of generating units to operate continuously and deliver electricity according to planned capacity over a specified period. Reliability represents a critical dimension of power system performance because failures or unplanned outages can disrupt electricity supply, increase operational costs, and compromise system stability. Common indicators used to measure reliability include the Equivalent Availability Factor (EAF), which reflects the proportion of time a unit is available for operation, and the Equivalent Forced Outage Rate (EFOR), which measures the frequency and duration of unplanned outages (Siswanti et al., 2024).

High reliability performance is closely associated with effective maintenance management and asset integrity. Inadequate maintenance planning and insufficient allocation of resources to critical equipment significantly increase the probability of forced outages. Conversely, risk-based maintenance strategies that prioritize high-impact assets improve availability and reduce operational disruptions (Nguyen, 2024). Therefore, enhancing reliability is widely recognized as a primary objective of maintenance optimization in power plant operations.

Maintenance Budget Optimization

Maintenance budget optimization is a managerial approach aimed at allocating financial resources efficiently to maximize asset performance while minimizing lifecycle costs. Traditional maintenance budgeting methods often rely on historical expenditure patterns or fixed allocations that fail to reflect current asset conditions and operational risks, leading to inefficient resource utilization (Zhang, 2024).

Modern maintenance management emphasizes risk-based and performance-based approaches, such as Reliability-Centered Maintenance (RCM), which focuses on identifying critical assets, analyzing failure modes, and prioritizing maintenance actions based on risk severity. Aligning maintenance budgets with asset criticality ensures that limited financial resources are directed toward components with the greatest impact on reliability and operational continuity (Prabowo et al., 2025).

Empirical evidence indicates that optimized maintenance budgeting reduces unexpected failures, lowers corrective maintenance costs, and extends asset lifespan. Moreover, maintenance budget optimization supports strategic decision-making by integrating financial planning with technical performance indicators. In large-scale power plants, this approach is particularly important due to equipment complexity and the high economic consequences of unplanned outages (Nguyen, 2024).

Sustainability and Energy Efficiency in Power Plant Operations

Sustainability in power plant operations extends beyond emission control to include energy efficiency, resource conservation, and environmentally responsible asset management. Improving internal energy efficiency reduces operational costs while enhancing

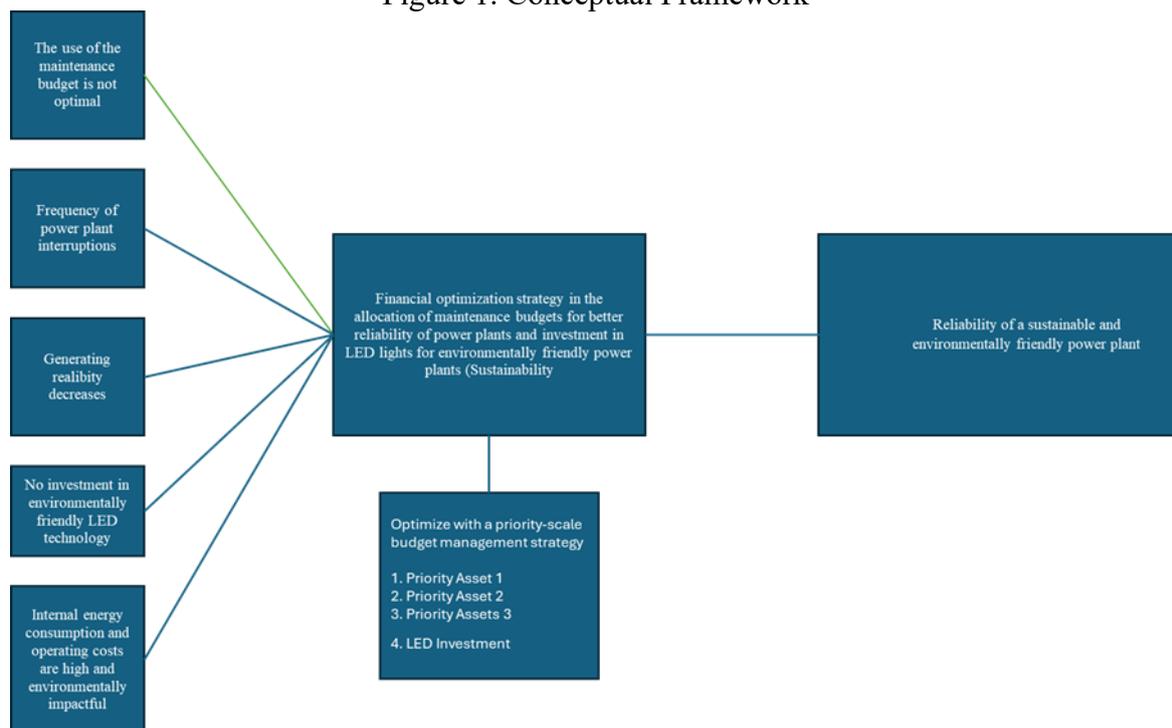
environmental performance (Chien, 2022). One area with significant efficiency improvement potential is auxiliary power consumption, including facility lighting systems.

LED lighting technology has emerged as an effective solution for reducing energy consumption and environmental impact. Compared with conventional lighting systems, LEDs consume less electricity, offer longer operational lifespans, and require less frequent replacement. Additionally, LED lamps do not contain hazardous materials such as mercury, which are commonly found in traditional lighting technologies. As a result, LED adoption supports both economic efficiency and environmental sustainability (Pizzichetti et al., 2024).

Previous research highlights the cost-effectiveness of LED implementation in industrial facilities, demonstrating reductions in energy costs and maintenance requirements over the equipment lifecycle. However, studies explicitly linking LED investment with broader reliability and sustainability strategies in power plant operations remain limited. Integrating energy-efficient technologies with maintenance optimization provides a holistic approach to improving operational performance while supporting long-term sustainability objectives (Siswanti et al., 2024).

Conceptual Framework

Figure 1. Conceptual Framework



METHOD

This study employs a case study approach using a mixed-methods research design that integrates qualitative and quantitative analyses to comprehensively evaluate strategies for strengthening power plant reliability and sustainability. The mixed-methods approach enables triangulation of findings by combining numerical performance data with contextual and managerial insights, thereby enhancing analytical robustness and interpretative depth.

Research Design

This research is designed as an applied case study focusing on PLTU Suralaya Units 5–7, one of the largest coal-fired power plants in the Java–Bali electricity system. The study evaluates operational performance before and after the implementation of maintenance budget optimization and LED lighting investment. This comparative design enables the assessment of changes in reliability indicators and sustainability-related outcomes over time.

Data Sources and Collection

The study utilizes both primary and secondary data sources.

Secondary data were obtained from internal company documents, including maintenance budget reports, operational disturbance records, reliability performance indicators (such as Equivalent Availability Factor (EAF) and Equivalent Forced Outage Rate (EFOR)), and environmental management data covering the period 2020–2025.

Primary data were collected through field observations and informal interviews with maintenance and operational personnel to obtain qualitative insights into maintenance practices, operational challenges, and sustainability initiatives.

Research Variables and Indicators

The key variables examined in this study include maintenance budget optimization, power plant reliability, and sustainability performance. Maintenance budget optimization is evaluated through changes in budget allocation patterns based on asset criticality and maintenance priorities. Power plant reliability is assessed using reliability performance indicators, particularly the Equivalent Availability Factor (EAF) and the Equivalent Forced Outage Rate (EFOR), which reflect unit availability and the frequency of forced outages. Sustainability performance is evaluated based on reductions in internal energy consumption for lighting systems, improvements in operational cost efficiency, and the decrease in hazardous waste generated by conventional lighting. These variables are analyzed to identify the relationship between maintenance budget optimization, LED investment, and overall operational performance.

Data Analysis Techniques

Several analytical techniques were employed to address the research objectives.

SWOT analysis was used to identify internal strengths and weaknesses as well as external opportunities and threats related to maintenance management and sustainability initiatives.

The SWOT results were subsequently evaluated using the Internal Factor Evaluation (IFE) and External Factor Evaluation (EFE) matrices to determine the strategic positioning of the power plant.

In addition, time series analysis was conducted to examine trends in reliability performance and maintenance costs over the study period. This analysis enables comparison of operational conditions before and after the implementation of the proposed strategies, providing empirical evidence of their effectiveness.

Research Validity and Reliability

To enhance the validity and reliability of the findings, data triangulation was applied by cross-referencing quantitative operational data with qualitative insights obtained from field observations and interviews. The use of multiple data sources and analytical techniques reduces potential bias and strengthens the credibility of the research conclusions.

RESULTS AND DISCUSSION

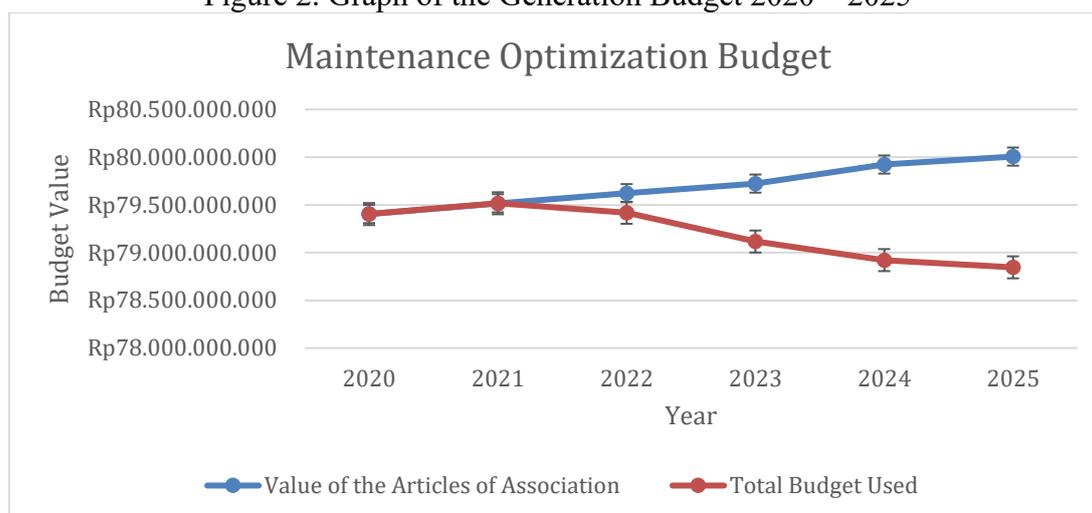
Results

Maintenance Budget Optimization and Reliability Performance

Analysis of maintenance budget allocation at PLTU Suralaya Units 5–7 indicates that prior to optimization, maintenance expenditures were primarily based on historical spending patterns rather than asset criticality and operational risk considerations. This approach resulted in a relatively uniform distribution of maintenance resources across equipment, regardless of their impact on operational reliability. Consequently, several critical assets did not receive adequate preventive maintenance, leading to frequent unplanned outages and declining reliability performance.

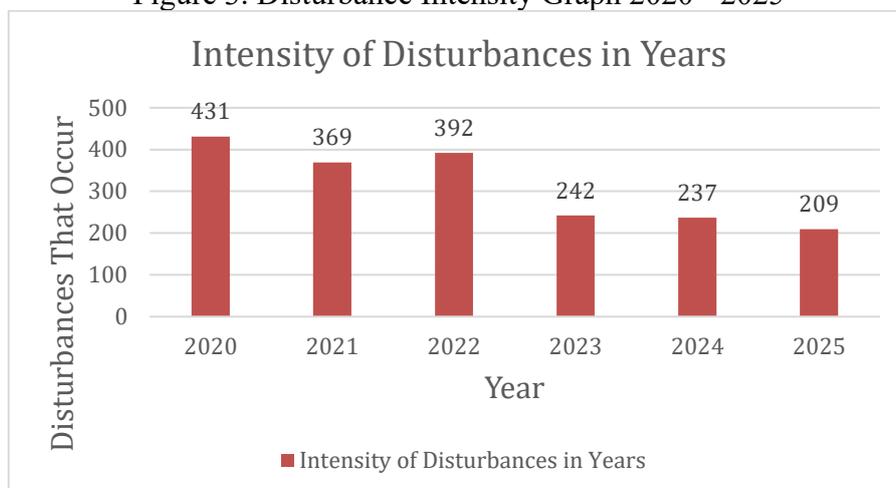
Following the implementation of a maintenance budget optimization strategy, financial resources were allocated based on critical asset priorities. This approach not only reduced operational costs but also enabled the reallocation of efficiency gains to support sustainability initiatives, including the replacement of conventional lighting with LED technology. This dual impact resulted in cost savings while simultaneously improving energy efficiency.

Figure 2. Graph of the Generation Budget 2020 – 2025



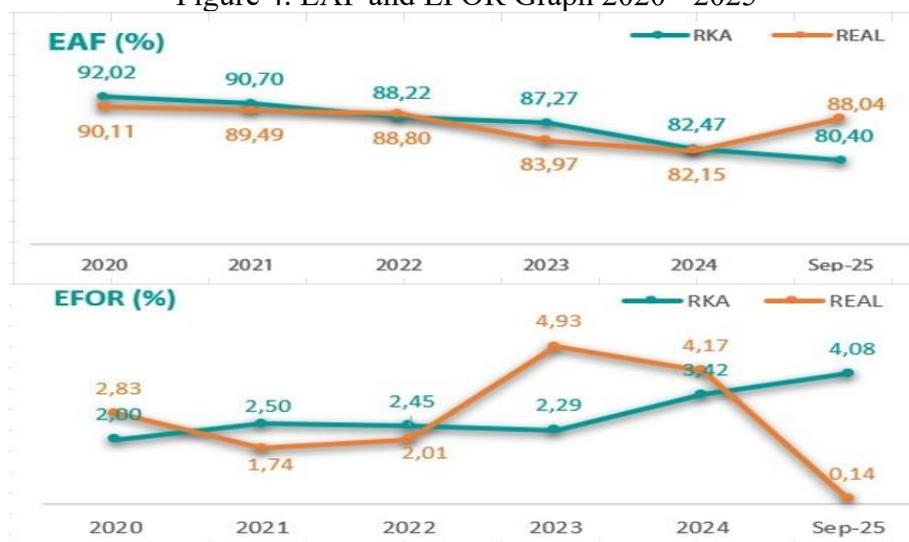
After optimization was implemented, maintenance effectiveness improved significantly. Preventive maintenance activities became more focused on high-risk and high-impact equipment, reducing reliance on corrective maintenance and minimizing operational disruptions.

Figure 3. Disturbance Intensity Graph 2020 - 2025



Time series analysis of operational performance data indicates an upward trend in the Equivalent Availability Factor (EAF) and a corresponding decrease in the Equivalent Forced Outage Rate (EFOR). These trends reflect improved unit availability and reduced forced outages after the optimization strategy was applied.

Figure 4. EAF and EFOR Graph 2020 - 2025

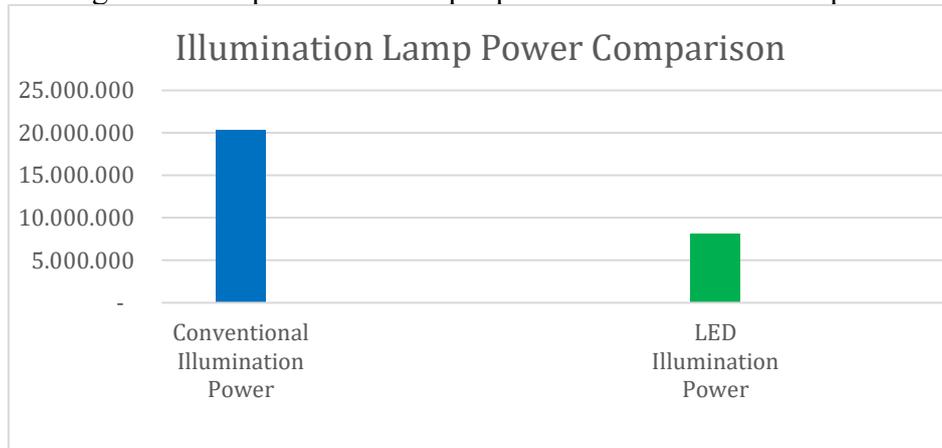


Overall, the findings demonstrate that maintenance budget optimization functions not only as a financial control mechanism but also as a strategic tool that directly enhances operational reliability.

LED Lighting Investment and Sustainability Performance

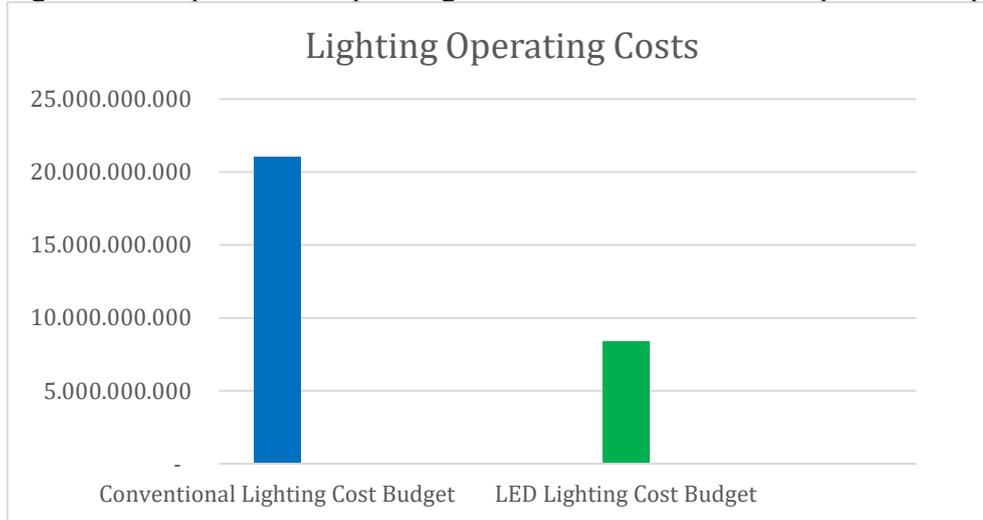
The results of the LED lighting investment analysis reveal substantial improvements in sustainability-related performance indicators. The replacement of conventional lighting systems with LED technology significantly reduced internal electricity consumption for lighting purposes. This reduction lowered auxiliary power usage and improved overall energy efficiency within the plant.

Figure 5. Comparison of Lamp Operational Power Consumption



In addition to energy savings, LED adoption reduced operational and maintenance costs. LED lamps have longer service lifetimes and require less frequent replacement compared with conventional lighting systems, thereby lowering material procurement and labor costs. Furthermore, the transition to LED lighting significantly reduced hazardous waste generation, particularly mercury-containing lamps, supporting environmentally responsible waste management practices.

Figure 6. Comparison of Operating Costs of Conventional Lamps and Lamps



These results confirm that LED lighting investment provides tangible economic and environmental benefits, reinforcing its role as an effective sustainability initiative in power plant operations.

Discussion

The findings highlight the effectiveness of integrating maintenance budget optimization and LED lighting investment as a unified strategy to enhance both reliability and sustainability performance. From a reliability perspective, prioritizing maintenance expenditures based on

asset criticality reduces forced outages and improves availability indicators, supporting previous research emphasizing the importance of risk-based maintenance management.

This study extends existing literature by demonstrating that maintenance budget optimization can function as a financial enabler for sustainability initiatives. Rather than treating reliability improvement and sustainability enhancement as separate objectives, the integrated approach shows that efficiency gains from optimized maintenance budgeting can be strategically reallocated to support energy-efficient investments such as LED lighting. This integrated managerial perspective strengthens the novelty and practical relevance of the study.

From a sustainability standpoint, the adoption of LED lighting illustrates how relatively modest technological investments can generate significant operational and environmental benefits. Reduced internal energy consumption contributes to lower operational emissions, while the elimination of mercury-based lighting reduces environmental and health risks associated with hazardous waste. These outcomes align with corporate sustainability objectives and national commitments to energy efficiency and environmental protection.

Overall, the results confirm that the proposed integrated strategy provides a practical and scalable pathway for improving reliability and sustainability in large-scale power plants. Evidence from PLTU Suralaya Units 5–7 demonstrates that financial optimization and technological innovation can be effectively combined to achieve sustainable operational excellence.

CONCLUSION

This study demonstrates that maintenance budget optimization combined with LED lighting investment constitutes an effective integrated strategy for enhancing both reliability and sustainability in large-scale power plant operations, as evidenced in PLTU Suralaya Units 5–7. Reallocating maintenance budgets based on asset criticality improved preventive maintenance effectiveness, reduced forced outages, and strengthened overall operational reliability, as reflected in improved availability indicators.

The findings further indicate that efficiency gains derived from optimized maintenance budgeting can be strategically redirected to support sustainability-oriented investments. The implementation of energy-efficient LED lighting significantly reduced internal electricity consumption, lowered operational and maintenance costs, and minimized hazardous waste generated by conventional lighting systems. These outcomes confirm that sustainability initiatives can deliver tangible operational and financial benefits when integrated within a reliability-focused management framework.

From a managerial perspective, this research provides practical insights for power plant operators and decision-makers. Maintenance budget optimization should be viewed not merely as a cost-control mechanism but as a strategic instrument capable of enabling broader sustainability initiatives. The integrated approach proposed in this study offers a practical pathway for balancing operational reliability, cost efficiency, and environmental responsibility in power plant management.

Despite its contributions, this study has limitations. The analysis is based on a single case study at PLTU Suralaya Units 5–7, which may limit the generalizability of the findings to other power plants with different technologies or operational contexts. Additionally, the study relies on historical operational and financial data that may be influenced by site-specific

managerial and technical conditions. Future research may extend this framework by examining multiple power plants, conducting comparative analyses, or exploring additional sustainability technologies to further validate and refine the proposed integrated strategy.

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