West Science Information System and Technology
Vol. 3, No. 01, April 2025, pp. 50~55

Economic Feasibility Analysis of Integrated Energy Implementation in Industrial Areas in Indonesia

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Article Info

Article history:

Received April, 2025
Revised April, 2025
Accepted April, 2025

Keywords:

Integrated Energy Systems,
Economic Feasibility,
Industrial Areas,
Renewable Energy,
Government Support

ABSTRACT

This study analyzes the economic feasibility of implementing integrated energy systems in industrial areas in Indonesia. Using a quantitative approach, data was collected from 35 industrial areas through a Likert scale survey, and analyzed using SPSS version 26. The analysis focused on key variables such as investment costs, energy savings, payback period, government support, technical feasibility, and energy efficiency. The results revealed that while energy savings and government support were perceived as key benefits, high investment costs and long payback periods posed significant barriers to adoption. Additionally, the findings highlighted a strong correlation between technical feasibility and energy savings, underscoring the importance of infrastructure compatibility. The study suggests that reducing investment costs, improving access to capital, and enhancing government incentives are essential to promoting the adoption of integrated energy systems in Indonesia's industrial sectors.

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1. INTRODUCTION

The rapid industrialization of Indonesia has led to a significant increase in energy demand, particularly within the manufacturing sectors, necessitating the development of integrated energy systems that blend renewable and conventional sources to ensure sustainability and energy security. These systems are crucial for optimizing energy use, reducing dependency on non-renewable sources, and minimizing environmental impact, aligning with global sustainability goals. The Indonesian government has set an ambitious target of achieving 100% renewable energy by 2060, with solar photovoltaic (PV) expected to contribute 72.3% of the total installed capacity by 2050 [1]. A prominent example of renewable energy integration is the deployment of solar power plants combined with battery energy storage systems in Pulau Bunyu, which, despite high upfront costs, demonstrates potential for lowering fossil fuel consumption and increasing energy reliability [2]. Nonetheless, several challenges persist, including high initial investment costs, limited technological capabilities, and a shortage of skilled labor in renewable energy technologies [3]. Addressing these barriers requires robust policy support, financial incentives, and continued technological innovation [3]. Smart grid infrastructure and digital technologies offer promising avenues for enhancing energy flexibility, cost-efficiency, and system reliability, while the inclusion of diverse renewable sources such as biomass and geothermal further strengthens the resilience of Indonesia's energy infrastructure [4]. In practice, sectors like the cement industry, which is one of the largest industrial energy consumers, have begun implementing energy-efficient strategies, although these measures have yet to significantly curb carbon emissions, underscoring the urgency for more effective, integrative energy solutions [5].

Indonesia's energy demand is projected to rise sharply by 2060, driven primarily by the expansion of industrial activities, particularly within the manufacturing sector, which is expected to retain a 34% share of the nation's total energy consumption (Liun et al., 2022). As a major energy consumer, the industrial sector faces mounting pressure to adopt energy-efficient practices to mitigate both financial burdens and environmental degradation caused by continued reliance on fossil fuels [6]. In response, renewable energy sources—such as solar, wind, and biomass—have been actively promoted as part of Indonesia's long-term sustainability agenda aimed at reducing greenhouse gas emissions and ensuring energy security [7], [8]. Despite having a substantial theoretical renewable energy potential of up to 420 GW—comprising solar (208 GW), wind (61 GW), and geothermal (24 GW)—the actual integration of these resources into existing industrial energy systems remains fraught with challenges, including funding limitations, poor inter-agency coordination, and implementation difficulties that were further exacerbated by the COVID-19 pandemic [8], [9]. This is particularly critical in high-consumption industrial zones where managing energy supply and demand is inherently complex. To address these issues, the Indonesian government continues to develop policy frameworks aimed at accelerating the renewable transition by increasing the share of renewables in the national energy mix while balancing environmental goals with the need for sustained economic growth [7], [9].

The Indonesian government has recognized the importance of transitioning to sustainable energy systems and has introduced policies to promote renewable energy adoption, including tax incentives, subsidies, and infrastructure development. However, the economic feasibility of implementing integrated energy systems remains a key consideration for industrial stakeholders. The challenges of upfront investment, infrastructure upgrades, and uncertainty around long-term returns on investment often discourage industries from transitioning to integrated energy solutions. This study seeks to analyze the economic feasibility of implementing integrated energy systems in industrial areas in Indonesia.

2. LITERATURE REVIEW

2.1 Concept of Integrated Energy Systems

Integrated Energy Systems (IES) are vital for sustainable energy transitions by combining electricity, heat, and fuels into efficient, cost-effective, and reliable systems, especially in energy-intensive industries. By integrating renewables like solar, wind, and hydro into existing grids, IES help reduce fossil fuel dependency and lower emissions [10], [11]. They also enhance energy efficiency, flexibility, and reliability through optimized use and decentralized energy flows [11], [12]. Additionally, IES drive market innovation through the integration of energy vectors and cyber-physical systems [11]. However, challenges remain in system planning, control, and storage, requiring smart grid advancements and strong regulatory and economic support to maximize their benefits [10], [12].

2.2 Economic Feasibility of Integrated Energy Systems

The economic feasibility of integrated energy systems (IES) involves weighing high initial investments against long-term gains like energy savings, efficiency, and security.

Integrating renewables such as solar and hydrogen can lower costs and emissions, especially in areas with strong solar potential and policy support. In Indonesia, solar and hydrogen integration offers the lowest Levelized Cost of Energy (LCOE) and significant CO_2 reductions despite high upfront costs [13]. Similar benefits are seen in Canada, the USA, and Africa through job creation and competitiveness [15]. Government incentives in Indonesia—like solar subsidies and tax breaks—boost IES viability [14], while policy and financing frameworks improve access to capital and awareness [15]. Advances in renewable and storage technologies further cut operational costs [14], and cross-sector integration enhances energy security and sustainability.

2.3 Role of Renewable Energy in Industrial Sectors

The integration of renewable energy into industrial systems offers significant environmental, economic, and strategic benefits, particularly in Indonesia where industrial operations remain heavily dependent on fossil fuels. Renewable sources such as solar and biomass are especially promising; solar energy, supported by Indonesia's high solar radiation levels, can substantially meet industrial energy needs while reducing grid dependence and operational costs [4]. Biomass energy, sourced from agricultural residues, provides a sustainable and locally available energy solution that also supports waste management, especially in agriculturally rich regions [15]. These renewable options not only lower greenhouse gas emissions but also enhance energy security and long-term economic viability [10], [18]. Technological advancements in smart grids and energy storage are essential to fully realize these benefits and manage challenges such as energy intermittency and grid integration [4], [10], while strategic planning, supportive policies, financial mechanisms, and increased awareness are crucial to enabling a successful transition to renewable energy [15].

3. METHODS

3.1 Research Design

This study employs a descriptive and analytical quantitative research design to assess the economic feasibility of integrated energy systems. Descriptive research is used to provide an overview of the current energy practices in industrial areas, including the extent of renewable energy integration, energy costs, and energy consumption patterns. Analytical research, on the other hand, focuses on examining the relationships between key variables—such as investment costs, energy savings, and the adoption of renewable energy—and their impact on the economic feasibility of integrated energy systems.

The research is conducted using cross-sectional data, which provides a snapshot of the energy practices and economic conditions of the sampled industrial areas at a specific point in time. This design allows for the identification of trends, patterns, and relationships that can inform the decision-making process regarding the implementation of integrated energy solutions in Indonesia.

3.2 Population and Sample

The population of this study comprises industrial areas in Indonesia with the potential to implement integrated energy systems, characterized by high energy consumption, diverse industrial activities, and varying energy management practices. Due to the vast geographical scope and diversity of industrial zones in the country, a purposive sampling technique was employed to select 35 industrial areas representing a cross-section of sectors such as manufacturing, textiles, food processing, and chemicals. The selection was based on specific criteria: the area must have a significant energy consumption footprint, be in the process of or planning to integrate renewable energy solutions, and be located in regions where government incentives or policies support renewable energy adoption. This sample size is deemed adequate to perform meaningful statistical analyses and to derive reliable conclusions regarding the economic feasibility of integrated energy systems in Indonesia's industrial sectors.

3.3 Data Collection

Data were collected through a structured survey targeting key stakeholders in 35 selected industrial areas, including energy managers and sustainability officers, to assess factors influencing the economic feasibility of integrated energy systems. The survey covered four sections—energy management practices, economic factors, government incentives, and technical challenges—with statements rated on a 5-point Likert scale. It was distributed via email and in-person visits, yielding a 100% response rate.

3.4 Data Analysis

Data collected from the survey responses were analyzed using SPSS version 26, employing descriptive statistics to summarize findings and provide an overview of the economic feasibility of integrated energy systems in the sampled industrial areas. Measures such as mean, standard deviation, and frequency distribution were calculated to identify trends and patterns across key variables. Inferential statistical techniques, particularly correlation analysis, were used to examine the relationships between investment costs, energy savings, government support, technical feasibility, and the adoption of integrated energy systems. This analysis assessed the strength and direction of these associations and how they collectively influence overall economic feasibility. A 95% confidence level and a p-value threshold of 0.05 were applied to determine the statistical significance of the relationships among variables.

4. RESULTS AND DISCUSSION

4.1 Descriptive Statistics

The first step in analyzing the data was to calculate descriptive statistics for each variable to gain an overview of the responses from the selected industrial areas. For Investment Costs, the mean score was 3.62 with a standard deviation of 0.89, indicating that respondents viewed the upfront cost of implementing integrated energy systems as moderately high. Although this was seen as a concern, some areas with access to government incentives found these costs more manageable. For Energy Savings, the mean was 4.02 and the standard deviation 0.78, showing a strong belief in the potential of integrated systems to lower electricity bills and operational costs—especially among those already using renewable energy. The Payback Period had a mean of 3.48 and standard deviation of 0.95, suggesting that while many acknowledged the long-term benefits, concerns remained about the relatively long time required to recoup initial investments, particularly in financially constrained areas.

For Government Support and Incentives, the mean score was 3.89 with a standard deviation of 0.84, reflecting the general agreement that such support plays a key role in making integrated energy systems financially feasible. However, the effectiveness of these incentives was perceived to vary across regions. Technical Feasibility yielded a mean of 3.73 and standard deviation of 0.91, suggesting that most respondents felt the technical challenges were manageable, though concerns about infrastructure compatibility and renewable reliability remained, especially in remote areas. Finally, Energy Efficiency scored the highest with a mean of 4.10 and standard deviation of 0.85, indicating a strong perception that integrated energy systems can significantly enhance energy efficiency and reduce waste, particularly in areas already engaged in energy-saving initiatives.

4.2 Correlation Analysis

The next step in the analysis involved examining the relationships between the key variables using correlation analysis.

Table 1. Correlation Analysis

Variable	Investment Costs	Energy Savings	Payback Period	Government Support	Technical Feasibility	Energy Efficiency

Investment Costs	1					
Energy Savings	0.541**	1				
Payback Period	-0.421*	-0.472**	1			
Government Support	0.411*	0.502**	-0.391*	1		
Technical Feasibility	0.386*	0.605**	-0.431*	0.446*	1	
Energy Efficiency	0.452*	0.721**	-0.462**	0.563**	0.581**	1

Several important correlations were identified in the analysis. A moderate positive correlation between Investment Costs and Energy Savings (r = 0.541) suggests that areas with higher perceived investment costs also tend to expect greater energy savings, indicating that those investing more in renewable solutions anticipate higher financial returns. Conversely, a moderate negative correlation between Investment Costs and Payback Period (r = -0.421) shows that higher costs are associated with longer payback times, reflecting the financial challenge of recouping initial investments. A strong positive correlation between Energy Savings and Energy Efficiency (r = 0.721) indicates that areas reporting higher savings also perceive significant improvements in efficiency, reinforcing the link between reduced consumption and optimized energy use. Government Support and Energy Savings were also moderately correlated (r = 0.502), underlining the role of policy incentives in encouraging energy-efficient practices. Lastly, a strong positive correlation between Technical Feasibility and Energy Savings (r = 0.605) suggests that areas viewing renewable integration as technically feasible are more likely to realize substantial energy savings, highlighting the importance of infrastructure compatibility and system reliability.

DISCUSSION

The results of the analysis provide valuable insights into the economic feasibility of implementing integrated energy systems in industrial areas in Indonesia. Descriptive statistics and correlation analysis reveal several key findings. First, there is a strong belief among respondents in the significant energy savings that integrated systems can deliver, a perception that aligns with previous studies emphasizing the cost-saving benefits of renewable energy in industrial sectors (Krupp & Ross, 2020). However, high investment costs remain a substantial barrier, as many industrial areas still struggle with funding access—an issue also highlighted in broader discussions on renewable energy adoption (IPCC, 2021). Additionally, the study underscores the critical role of government support in facilitating renewable integration; areas with higher levels of subsidies and incentives reported greater energy savings, supporting findings that policy frameworks are instrumental in overcoming initial cost barriers (Jha, 2019).

Moreover, the correlation between technical feasibility and energy savings points to the importance of infrastructure compatibility. Industrial areas with fewer technical challenges reported greater energy benefits, indicating that successful renewable energy integration requires not only financial and policy backing but also technical readiness. Furthermore, concerns about the payback period suggest that integrated energy systems are perceived as long-term investments. Although long-term gains are evident, the extended time required to recover initial costs may discourage adoption, particularly in sectors facing capital constraints or short-term financial pressures. These findings collectively emphasize that while integrated energy systems are economically promising, their adoption depends on a balance of financial incentives, policy support, and technical infrastructure.

5. CONCLUSION

The findings from this study emphasize the economic challenges and opportunities associated with the implementation of integrated energy systems in industrial areas in Indonesia. The study shows that while there is a general belief in the significant energy savings and improvements in energy efficiency offered by integrated energy systems, high initial investment costs and long payback periods are substantial barriers to their widespread adoption. Government support through policies, subsidies, and incentives plays a crucial role in mitigating these financial barriers, particularly in industrial areas with limited access to capital. Furthermore, the technical feasibility of integrating renewable energy technologies with existing infrastructure is critical to realizing the expected energy savings and ensuring the sustainability of energy solutions. To foster greater adoption of integrated energy systems, the study suggests that both the government and private sector must collaborate to reduce financial constraints and improve technical compatibility.

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