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9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Techno-Economic Optimization of Diesel–PV Hybrid Systems for Isolated Island Grids: Case Study of Tomia Island, Indonesia

Romi Adi Sanjaya Sebayang[1*], **Wawan Aries Widodo**[1]

[1] Master of Mechanical Engineering in Mechanical Systems Design Program, Sepuluh Nopember Institute of Technology, 60111, **Indonesia**

* 6007241016@student.its.ac.id

Abstract

Tomia Island, an isolated power system in Wakatobi Regency, Indonesia, relies primarily on diesel power generation, resulting in high operating costs, fuel dependency, and greenhouse gas emissions. Although the island has abundant solar energy resources, determining an appropriate photovoltaic (PV) capacity that balances technical performance, economic feasibility, and land availability remains a key challenge. This study aims to identify the optimal hybrid PV–diesel configuration to support a reliable and sustainable electricity supply. The analysis combined solar resource assessment, land suitability evaluation, and energy system modeling using the Low Emissions Analysis Platform (LEAP). Several development scenarios were compared to identify the most suitable system configuration based on technical and economic performance. The results indicate that a 2.5 MWp PV system integrated with a 4 MWh Battery Energy Storage System (BESS) provides the best balance between renewable energy utilization, system reliability, and investment cost. Compared with larger PV capacities, this configuration delivers substantial reductions in diesel fuel consumption and carbon emissions while avoiding unnecessary increases in investment and excess energy production. In addition, the integration of BESS improves supply reliability by storing surplus solar energy and supplying electricity during periods of low solar generation. Economic evaluation confirms that the proposed hybrid system is financially feasible, offering a competitive cost of electricity and a relatively short investment payback period. These findings demonstrate that the proposed PV–BESS–diesel configuration provides a practical and cost-effective pathway for reducing diesel dependence and accelerating the energy transition in isolated island power systems.

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1. Introduction

Indonesia is experiencing a continuous increase in electricity demand driven by economic growth, industrial development, and infrastructure expansion. According to the Electricity Supply Business Plan [1], national electricity consumption reached 306,130 GWh and is projected to continue growing over the next decade [2]. However, the national power sector remains heavily dependent on fossil fuels, which account for approximately 84.3% of total electricity generation. This dependence contributes to greenhouse gas (GHG) emissions, energy security concerns, and vulnerability to global fuel price fluctuations [3].

As part of its commitment under the Enhanced Nationally Determined Contribution (ENDC), Indonesia has targeted a reduction in GHG emissions by 31.89% through domestic efforts and up to 43.20% with international support. Consequently, the development of renewable energy has become a key strategy in supporting the national energy transition toward a cleaner and more sustainable energy system [4]. [5] reported that integrating Solar Photovoltaic (PV) systems with Diesel Power Plants (DPPs) in isolated power systems can reduce operational costs, decrease fuel consumption, and improve system sustainability. The projected growth trend of Indonesia's national electricity consumption based on the Electricity Supply Business Plan [1].

The trend shows a steady increase in electricity demand throughout the projection period, rising from approximately 305,000 GWh in 2025 to around 480,000 GWh in 2034, representing an overall increase of about 57%. Annual growth remains relatively consistent, indicating sustained expansion in electricity demand driven by economic development, industrialization, urbanization, and population growth. The demand exceeds 400,000 GWh by 2030 and continues to increase to more than 460,000 GWh by 2033. This upward trend highlights the growing pressure on the national power system to ensure adequate generation capacity, transmission infrastructure, and distribution reliability. Furthermore, the continuous increase in electricity consumption emphasizes the importance of accelerating renewable energy deployment, improving energy efficiency, and implementing long-term energy planning to maintain energy security while supporting national decarbonization targets.

Tomia Island, located in Wakatobi Regency, Southeast Sulawesi, operates as an isolated electricity system that relies primarily on the Wahatomia Diesel Power Plant to supply electricity. The system serves 3,471 customers across 17 villages, with an average electricity generation cost of IDR 4,387/kWh in 2023. This dependence on diesel generation results not only in high operating costs, logistical challenges associated with fuel transportation, and significant carbon emissions, but also increases operational risks related to fuel supply disruptions, equipment maintenance, and limited system flexibility during peak demand. These conditions may affect the reliability and affordability of electricity services for local communities and highlight the importance of improving the resilience of the island's power system. Therefore, the integration of Solar PV generation presents a promising alternative to enhance the efficiency, reliability, and sustainability of the island's electricity supply [6].

Previous studies have demonstrated the technical and economic benefits of hybrid Diesel–PV systems in isolated regions. [5] reported that a hybrid PV–Diesel configuration increased the renewable energy share by 26.6% in the Talaga Kecil Island power system. Similarly, [7] found that a Diesel–PV–Battery Energy Storage System (BESS) configuration on Karanrang Island reduced fuel consumption by 48.26%, lowered CO_2 emissions by 48%, and achieved an Internal Rate of Return (IRR) of 19.89%. These findings indicate that hybrid Diesel–PV systems represent a viable solution for supporting energy transition initiatives and achieving Indonesia's Net Zero Emissions target by 2060. Therefore, a techno-economic feasibility study is required to evaluate the potential development of a Diesel–PV hybrid system for the isolated power system of Tomia Island.

2. Methods

This study was conducted on the isolated power system of Tomia Island, Wakatobi Regency, Southeast Sulawesi, Indonesia, to evaluate the technical, economic, and environmental feasibility of integrating Solar Photovoltaic (PV) generation into the existing diesel-based electricity system. The objective was to identify the optimal hybrid PV–Diesel configuration that improves system performance while reducing fuel consumption and greenhouse gas emissions.

The research began with a literature review and the collection of operational data, including electricity demand, diesel generator specifications, solar irradiation, fuel consumption, emission factors, and investment and operating costs. These data were validated and used as inputs for energy system modeling in the Long-range Energy Alternatives Planning (LEAP) software.

Three development scenarios were evaluated: [8] the existing diesel-based system, [9] continuous diesel operation, and [10] a hybrid PV–Diesel system integrated with Battery Energy Storage System (BESS). The dispatch strategy prioritized electricity generated by the PV system to meet the load demand. Excess PV energy was stored in the BESS, while the diesel generators supplied electricity only when the available PV generation and stored battery energy were insufficient to satisfy the load demand. This operating strategy was adopted to maximize renewable energy utilization while maintaining supply reliability.

The scenarios were compared using technical, economic, and environmental performance indicators, including electricity generation, renewable energy penetration, diesel fuel consumption, greenhouse gas emissions, Net Present Cost (NPC), Levelized Cost of Energy (LCOE), Internal Rate of Return (IRR), and Payback Period (PP). The optimal configuration was selected based on its ability to provide the best balance between system reliability, economic feasibility, and environmental performance for isolated island power systems, as shown in **Figure 1**.

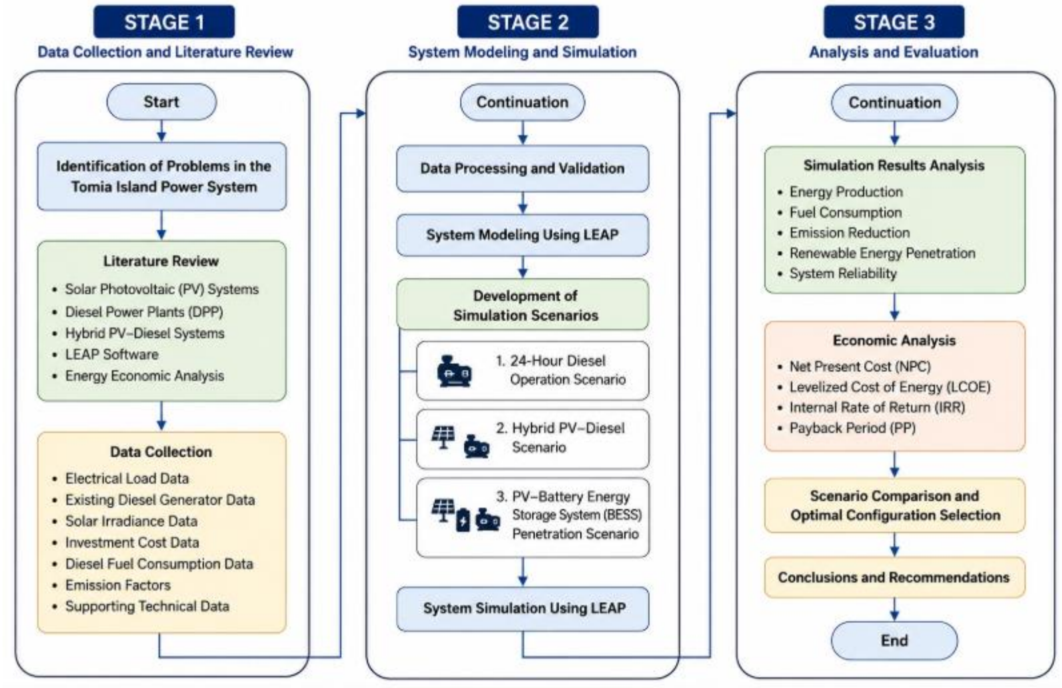

Figure 1. Flow Diagram

3.Results and Discussion

This section will systematically and structuredly explain how the research was conducted. The goal is to provide a clear overview of the research design and implementation to address the research problem formulation and achieve the stated objectives.

3.1 Project Location and Development Plan

This study was conducted on the isolated power system of Wahatomia Island, Wakatobi Regency, Southeast Sulawesi, Indonesia. The island was selected because it relies entirely on diesel power generation and has high solar energy potential, making it suitable for evaluating hybrid renewable energy systems.

According to the Project Feasibility Study (KKP), the proposed development consists of a 5.243 MWp Solar Photovoltaic (PV) power plant integrated with a 10.565 MWh Battery Energy Storage System (BESS). The project site is located in Wanci

Village, South Tomia District (5.729160° S, 123.906290° E) and is connected to the existing 20 kV Wahatomia distribution network, as shown in Figure 2.

The Wahatomia power system operates as an isolated grid without connection to the national transmission network and currently depends on diesel generators to supply electricity to 17 villages. This operating condition results in relatively high generation costs and dependence on diesel fuel.

The proposed hybrid PV–BESS–Diesel system is intended to increase renewable energy utilization while maintaining system reliability. The project has been included in PLN's Electricity Supply Business Plan (RUPTL) with a planned Commercial Operation Date (COD) in 2028. Additional technical specifications and project parameters are summarized in the Table 1.

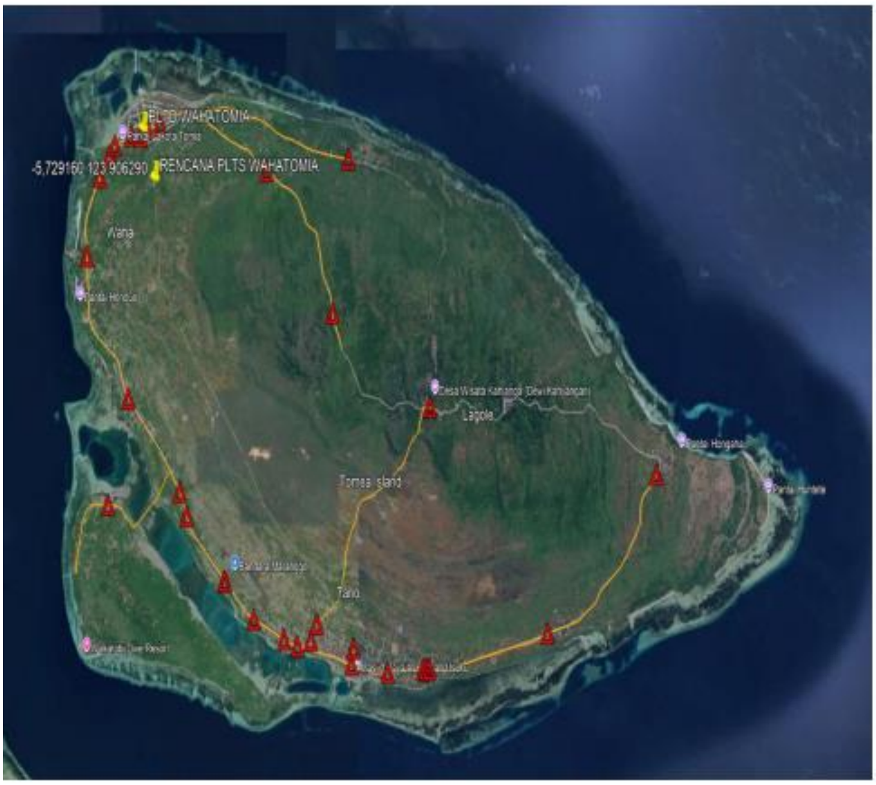

Figure 2. the Location of Wahatomia

3.2 Current System Condition with 24-Hour Operation Pattern

The existing electricity system on Tomia Island operates as an isolated grid supplied entirely by the Wahatomia Diesel Power Plant (DPP). The system serves customers in Tomia and East Tomia Districts, Wakatobi Regency, Southeast Sulawesi. The installed generation capacity is 3,192 kW, while the available capacity is 1,755 kW. Electricity is primarily supplied by the 1,300 kW Mitsubishi and 500 kW Cummins generator units, with the remaining units operating in standby, maintenance, or outage conditions.

The power system operates continuously for 24 hours to satisfy daily electricity demand. Based on operational data collected on 24 May 2026, the system load varied between 798 kW and 1,074 kW, with the evening peak occurring at 7:00 PM. This load pattern reflects the characteristics of a residential-dominated isolated power system.

Continuous reliance on diesel generation results in high fuel consumption, approximately 2,580 kL per year, and relatively high electricity production costs. In addition, aging generating units increase maintenance requirements and reduce operational flexibility. For example, one 800 kW Caterpillar generator is currently unavailable because of mechanical failure, increasing dependence on the remaining operational units.

The distribution system consists of approximately 30 km of medium-voltage lines and 31 distribution transformers with a combined capacity of 2,295 kVA. Although the network currently operates within acceptable voltage limits, integrating variable solar PV generation requires careful operational planning to maintain voltage stability, power balance, and reliable system operation. The addition of Battery Energy Storage System (BESS) is therefore expected to support load balancing, reduce diesel generator operating hours, and improve system flexibility during fluctuations in solar power generation.

These operational conditions demonstrate the need for a hybrid PV–BESS–Diesel system that can reduce fuel dependency while maintaining system reliability and supporting the long-term operation of isolated island power systems, as shown in **Figure 3**.

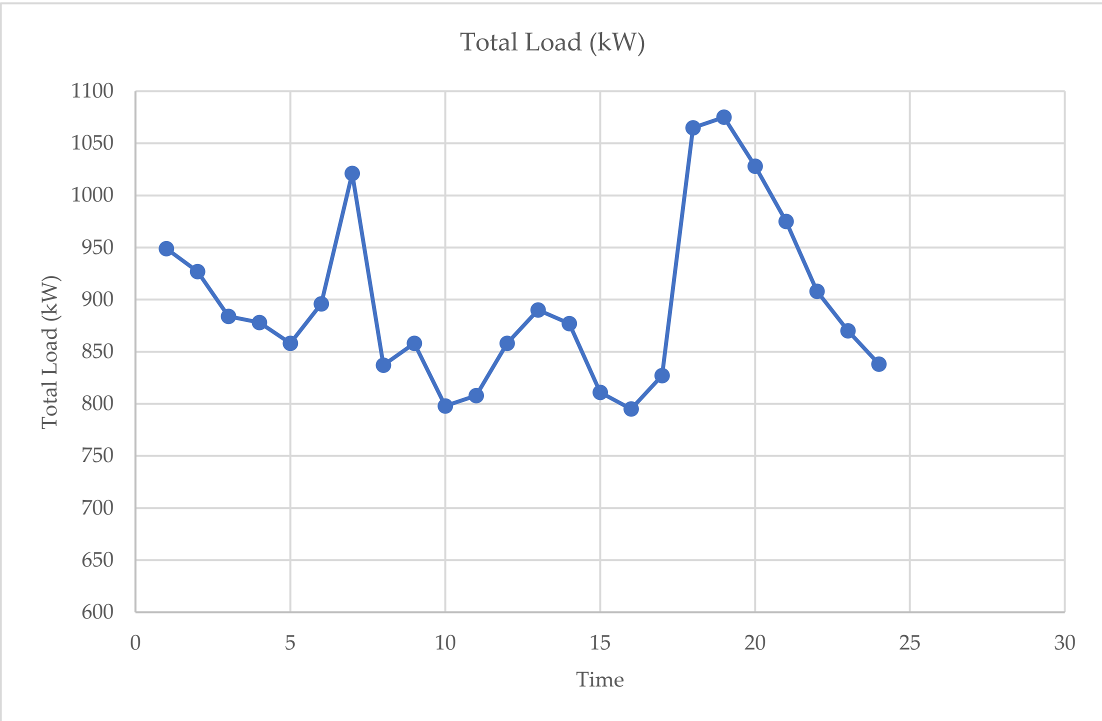

Figure 3. Graph of Daily Load Operation Pattern of Existing System

3.3 Scenario Analysis

The scenario analysis in this study was conducted using the Low Emissions Analysis Platform (LEAP) to evaluate the technical, economic, and environmental impacts of different power system development options for Tomia Island. LEAP enables long-term energy planning by simulating energy demand, electricity generation, fuel consumption, system costs, and greenhouse gas emissions under various development scenarios.

The analysis began with the collection of baseline data, including electricity load profiles, peak demand, diesel fuel consumption, generation capacity, operational data, customer growth, economic parameters, and emission factors. These data were used to develop the Current Accounts model representing the existing electricity system in the base year 2025, where the power supply is fully provided by diesel generators.

Subsequently, key assumptions were established to support long-term projections, including annual electricity demand growth, population growth, diesel fuel prices, inflation rates, discount rates, and emission factors. The demand module was then developed to forecast future electricity consumption based on customer growth and energy intensity assumptions.

The transformation module was used to model the electricity generation system, incorporating generator capacities, operational characteristics, efficiency, capacity factors, dispatch priorities, investment costs, and operation and maintenance costs. This module enables the simulation of both conventional and renewable energy technologies within the power system.

Three development scenarios were evaluated:

1. Business as Usual (BAU) – continued reliance on diesel generation as the primary electricity source.
2. Scenario 1 (Hybrid Diesel–PV) – integration of a 5.243 MWp Solar Photovoltaic (PV) power plant into the existing diesel-based system.
3. Scenario 2 (Hybrid Diesel–PV–BESS) – integration of a 5.243 MWp Solar PV power plant combined with a 10.565 MWh Battery Energy Storage System (BESS).

The simulation period covers 2025–2035. LEAP automatically calculates annual electricity generation, diesel fuel consumption, renewable energy penetration, reserve margins, carbon emissions, and total system costs for each scenario, as shown in **Figure 4**.

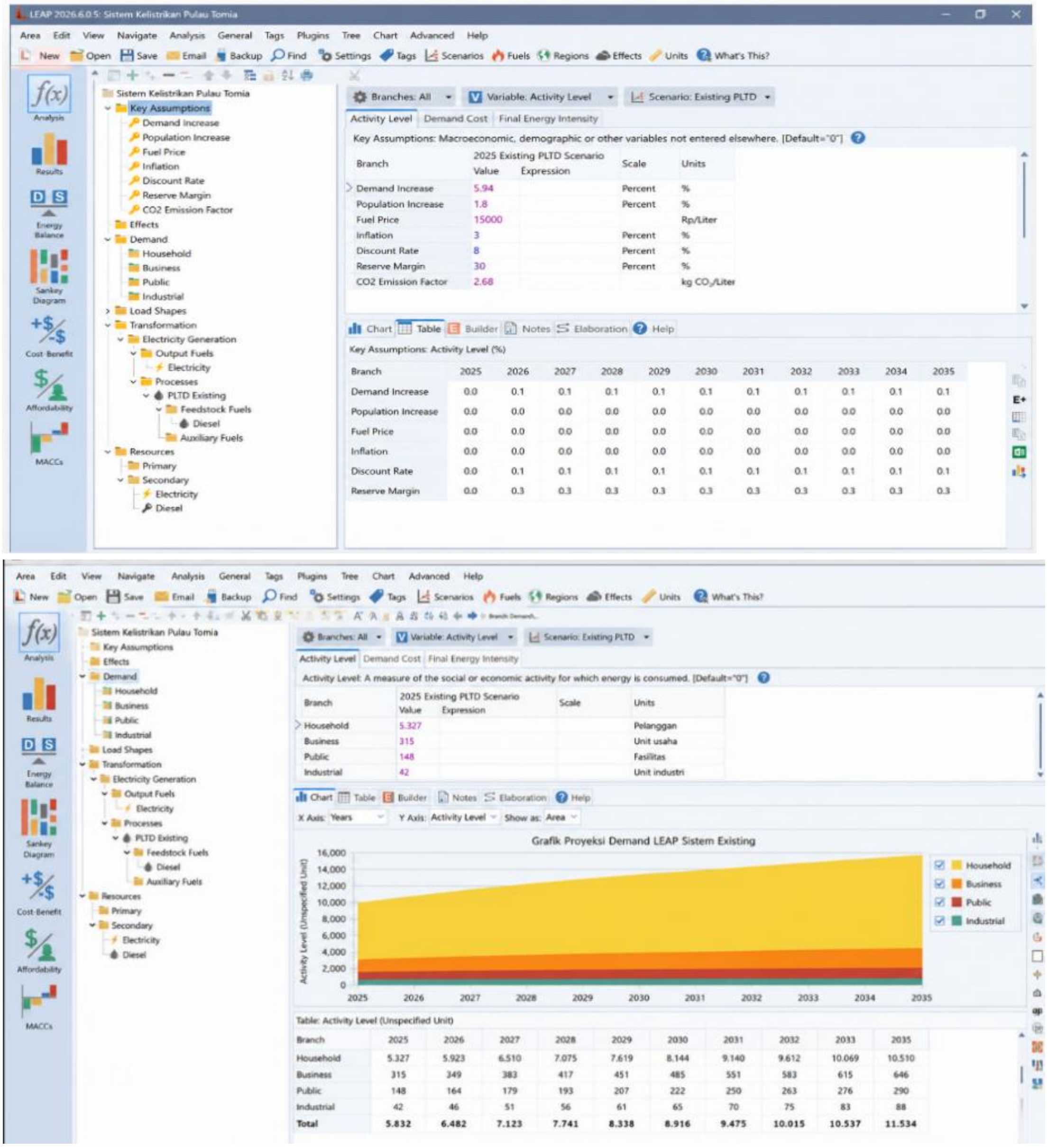

Figure 4. LEAP Scenario Exisiting PLTD 24 jam

Finally, the simulation results were compared using several key performance indicators, including fuel consumption, electricity production, renewable energy share, carbon emissions, Net Present Cost (NPC), Levelized Cost of Energy (LCOE), and Basic Production Cost (BPP). The comparison was conducted to identify the most technically feasible, economically attractive, and environmentally sustainable configuration for the Tomia Island power system.

Scenario analysis using the Low Emissions Analysis Platform (LEAP) was conducted to evaluate three alternative development pathways for the Tomia Island electricity system: Existing Diesel Power Plant (DPP) Operation, Hybrid Diesel–Solar PV System, and Optimized Solar PV–Battery Energy Storage System (BESS). The LEAP model was first validated using actual operational data to ensure that the simulation accurately represented the existing system conditions.

Existing Diesel Power Plant (DPP) Scenario

Under the existing condition, the Tomia Island power system relies entirely on diesel generators operating continuously for 24 hours. The system produces approximately 7.668 GWh/year of electricity and consumes around 2,580 kL of diesel fuel annually. As a result, the system generates approximately 6,914 tons of CO_2 emissions per year and has a relatively high electricity production cost of IDR 4,941/kWh. Since all electricity is generated from diesel fuel, the renewable energy fraction remains 0%, indicating complete dependence on fossil fuels.

Hybrid Diesel–Solar PV Scenario

The second scenario introduces a 5.243 MWp Solar Photovoltaic (PV) power plant integrated with the existing diesel system. The Solar PV system supplies electricity during daylight hours, thereby reducing diesel generator operation. Simulation results indicate that the Solar PV plant produces approximately 6.1 GWh/year, increasing the renewable energy fraction to 54%. Diesel fuel consumption decreases from 2,580 kL/year to 1,980 kL/year, resulting in annual fuel savings of approximately 600 kL. Furthermore, CO_2 emissions decrease from 6,914 tons/year to 5,306 tons/year, demonstrating significant environmental benefits.

Optimized Solar PV–Battery Energy Storage System (BESS) Scenario

The third scenario further enhances the hybrid system by integrating a 10.565 MWh Battery Energy Storage System (BESS). The battery stores excess solar energy generated during the day and supplies electricity during the evening and nighttime periods. Simulation results show substantial improvements, with the renewable energy fraction increasing to 72%. Diesel fuel consumption is reduced to approximately 920 kL/year, representing a reduction of more than 64% compared to the existing system. Annual CO_2 emissions decrease significantly to 2,466 tons/year, while fuel savings reach 1,660 kL/year. Electricity generation is supplied by Solar PV (6.1 GWh/year), BESS discharge (2.4 GWh/year), and diesel generators (2.8 GWh/year). This scenario provides the highest technical and environmental performance among all alternatives evaluated.

Renewable Energy Optimization Considering Land Constraints and Sustainability

Although a maximum renewable penetration scenario (5–6 MWp Solar PV and 10–12 MWh BESS) could achieve a renewable energy fraction of 85–95%, it would require substantial land area, higher investment costs, and increased battery waste generation. Therefore, an optimized and more sustainable configuration was evaluated. The results indicate that a system consisting of 2.5 MWp Solar PV and 4 MWh BESS represents the most practical solution for Wahatomia Island. This configuration achieves a renewable energy fraction of approximately 45%, reduces diesel consumption by 44.96%, lowers CO_2 emissions by 45%, and requires only 2.5

hectares of land. Consequently, it provides the best balance among technical performance, economic feasibility, environmental sustainability, and land-use constraints.

Table 1. Technical, Economic, and Operational Comparison of the Existing Diesel System, Hybrid DPP–PV System, and Optimized PV–BESS Configuration

Parameter	Existing DPP	Hybrid DPP–PV	Optimized PV–BESS (RF 45%)
Diesel Power Plant Capacity	4.1 MW	4.1 MW	4.1 MW
Solar PV Capacity	0 MWp	5.243 MWp	2.5 MWp
BESS Capacity	0 MWh	0 MWh	4 MWh
Annual Energy Demand	7.668 GWh	7.668 GWh	7.668 GWh
Peak Load	1.087 MW	1.087 MW	1.087 MW
Solar PV Energy Production	0 MWh	3.834 GWh	3.451 GWh
Diesel Energy Production	7.668 GWh	3.834 GWh	4.217 GWh
Renewable Energy Fraction	0%	50%	45%
Diesel Operating Hours	8,760 hours	6,100 hours	5,900 hours
Diesel Fuel Consumption	2,580 kL/year	1,290 kL/year	1,420 kL/year
Fuel Consumption Reduction	0%	50%	44.96%
CO_2 Emissions	6,914 tons/year	3,457 tons/year	3,803 tons/year
CO_2 Emission Reduction	0%	50%	45%
Night-Time System Reliability	High	Moderate	High
Energy Shifting Capability	None	None	Available
Dependence on Diesel Generation	Very High	Moderate	Low
Solar PV Land Requirement	0 ha	±5 ha	±2.5 ha
Energy Curtailment Potential	None	High	Low
Battery Waste Potential	None	None	Low–Moderate
Operational Complexity	Low	Moderate	High
Sustainability Level	Low	High	Very High

3.4 Comparison of Development Scenarios for the Tomia Island Power System

A comparative analysis was conducted to evaluate the performance of three electricity development scenarios for the Tomia Island isolated power system: [8] Existing Diesel Power Plant (DPP) Operation, [9] Hybrid Diesel–Solar PV System, and [10] Optimized Solar PV–Battery Energy Storage System (BESS) with a Renewable Fraction (RF) of 45%. The comparison was performed from technical, operational, economic, and environmental perspectives to identify the most suitable configuration for supporting energy transition on Tomia Island.

Technical Assessment

From a technical perspective, both renewable energy scenarios significantly improve system performance compared to the existing diesel-only system. Under the existing condition, all electricity demand is supplied by diesel generators, resulting in annual fuel consumption of 2,580 kL and CO_2 emissions of 6,914 tons. Although the system provides high reliability, it is highly dependent on fossil fuels and incurs substantial operating costs.

The Hybrid Diesel–PV scenario introduces a 5.243 MWp Solar PV plant, increasing the renewable energy fraction to approximately 50%. Diesel fuel consumption decreases to 1,290 kL/year, while CO_2 emissions are reduced by 50%. However, the absence of energy storage limits the utilization of excess solar energy during nighttime operation, leading to higher energy curtailment and requiring approximately 5 hectares of land.

The Optimized PV–BESS scenario consists of a 2.5 MWp Solar PV plant combined with a 4 MWh Battery Energy Storage System. Although the renewable energy fraction is slightly lower at 45%, the battery enables energy shifting by storing excess solar energy during the day and supplying electricity at night. Consequently, diesel operating hours decrease to approximately 5,900 hours per year, system reliability remains high, energy curtailment is minimized, and land requirements are reduced to approximately 2.5 hectares.

Overall, the Optimized PV–BESS configuration provides the best balance between renewable energy penetration, fuel savings, system reliability, land utilization, and long-term sustainability.

Operational Feasibility Assessment (KKO)

The Operational Feasibility Assessment indicates that integrating PV and BESS significantly improves operational efficiency. Compared with the existing system, diesel fuel consumption decreases from 2,580 kL/year to 1,420 kL/year, resulting in annual fuel savings of approximately 1,160 kL. The battery system enhances operational flexibility by allowing daytime solar energy to be stored and dispatched during evening peak-load periods, thereby reducing dependence on diesel generation and improving overall system performance.

Financial Feasibility Assessment (KKF)

Financial performance was evaluated using Net Present Cost (NPC), Levelized Cost of Energy (LCOE), and Payback Period (PP). The existing diesel-only system exhibits the highest lifecycle cost due to substantial fuel expenditures despite requiring no additional capital investment. The Hybrid Diesel–PV scenario reduces lifecycle costs and operational expenses; however, its performance remains limited by the absence of energy storage. In contrast, the Optimized PV–BESS scenario delivers the most favorable financial results. The total NPC decreases from IDR 1.03 trillion in the existing system to IDR 648.5 billion, while the LCOE decreases from IDR 5,373/kWh to IDR 3,383/kWh, representing a reduction of approximately 37%. Although the Optimized PV–BESS scenario requires the highest initial investment of IDR 58.5 billion, it achieves the shortest payback period of only 3.23 years due to substantial reductions in diesel fuel consumption and operating costs. The Hybrid Diesel–PV scenario requires an investment of IDR 42 billion and has a payback period of 4.42 years, as shown in Table 2.

Table 2. Operational Feasibility Study (KKO)

Parameter	Existing DPP	Hybrid DPP–PV	Optimized PV–BESS (RF 45%)
Diesel Power Plant Capacity	4.1 MW	4.1 MW	4.1 MW
Solar PV Capacity	0 MWp	5.243 MWp	2.5 MWp
BESS Capacity	0 MWh	0 MWh	4 MWh
Annual Energy Demand	7,668 MWh	7,668 MWh	7,668 MWh
Peak Load	1.087 MW	1.087 MW	1.087 MW
Solar PV Energy Production	0 MWh	3,834 MWh	3,451 MWh
Diesel Energy Production	7,668 MWh	3,834 MWh	4,217 MWh
Renewable Fraction	0%	50%	45%
Diesel Operating Hours	8,760 hours	6,100 hours	5,900 hours
Diesel Fuel Consumption	2,580 kL/year	1,290 kL/year	1,420 kL/year
Fuel Consumption Reduction	0%	50%	44.96%
CO_2 Emissions	6,914 tons/year	3,457 tons/year	3,803 tons/year
CO_2 Emission Reduction	0%	50%	45%
Night-Time System Reliability	High	Moderate	High
Energy Shifting Capability	None	None	Available
Dependence on Diesel Generation	Very High	Moderate	Low
Solar PV Land Requirement	0 ha	±5 ha	±2.5 ha
Energy Curtailment Potential	None	High	Low
Battery Waste Potential	None	None	Low–Moderate
Sustainability Level	Low	High	Very High

3.5 Main Findings of the Study

This study demonstrates that integrating renewable energy technologies substantially improves the performance of the Tomia Island isolated power system. Three development scenarios were evaluated using the Low Emissions Analysis Platform (LEAP), namely the Existing Diesel Power Plant (DPP), Hybrid DPP–Solar PV, and Optimized Solar PV–Battery Energy Storage System (BESS). The comparison shows that hybridization reduces diesel dependency, lowers greenhouse gas emissions, and improves the economic performance of electricity generation while maintaining system reliability.

The first major finding indicates that the existing Tomia Island power system remains highly dependent on diesel generation, resulting in high fuel consumption, elevated operating costs, and significant carbon emissions. Continuous operation of diesel generators also increases maintenance requirements and limits operational flexibility because generating units must operate throughout the day to satisfy electricity demand. These findings are consistent with those of [11], [12], who reported that isolated diesel-based power systems are characterized by high operating costs, low fuel efficiency, and substantial greenhouse gas emissions due to their dependence on fossil fuels.

The second finding shows that integrating Solar PV significantly improves system performance by replacing diesel generation during daylight hours. Consequently, diesel fuel consumption and carbon emissions are substantially reduced while renewable energy utilization increases. These operational improvements are consistent with the studies of [8], [13], [14], [15], which concluded that PV integration in isolated diesel grids improves fuel efficiency and reduces long-term operating costs. However, higher PV penetration also requires careful operational management to maintain voltage stability and power balance because solar generation is inherently intermittent.

A key contribution of this study is the identification of the 2.5 MWp PV with 4 MWh BESS configuration as the optimal solution, rather than the maximum PV capacity. Although the Hybrid DPP–PV scenario achieved a higher renewable fraction, the optimized PV–BESS configuration provided a better balance between renewable energy utilization, land requirements, investment cost, and operational reliability. The BESS enables excess daytime solar energy to be stored and dispatched during periods of low solar irradiance, thereby reducing diesel operating hours while maintaining supply reliability. This result supports the findings of [16], [17], who emphasized that hybrid system design should optimize the trade-off between renewable penetration, reliability, investment cost, and environmental performance rather than maximizing renewable capacity alone.

From an operational perspective, implementation of the PV–BESS system also introduces new challenges. Battery operation requires appropriate energy management, state-of-charge control, thermal monitoring, and periodic maintenance to ensure long-term performance. In addition, coordination between PV generation, battery dispatch, and diesel generators is essential to maintain frequency stability and reliable operation of the isolated grid. These practical considerations should be incorporated into future implementation planning by the utility.

Economic analysis indicates that the optimized PV–BESS scenario provides the most attractive financial performance among the evaluated alternatives. Lower Net Present Cost (NPC), reduced Levelized Cost of Energy (LCOE), and a relatively short payback period demonstrate that the selected configuration is both technically and economically feasible. These findings agree with those of [18]– [20], who demonstrated that PV–Diesel–Battery hybrid systems can achieve lower electricity costs and greater long-term economic benefits than conventional diesel-only systems.

This study also confirms the capability of LEAP as a practical decision-support tool for planning isolated power systems. By integrating demand forecasting, energy transformation, fuel consumption, greenhouse gas emissions, and economic evaluation within a single framework, LEAP enables planners to compare alternative development scenarios systematically. Similar conclusions were reported by [10], [21], who identified LEAP as an effective platform for long-term energy planning and energy transition analysis.

Overall, the results demonstrate that the optimized PV–BESS–Diesel configuration can reduce diesel fuel consumption and carbon emissions by approximately 45% while maintaining reliable electricity supply. These findings provide practical guidance for PLN in implementing diesel reduction programs on isolated islands and support Indonesia's Energy Transition agenda and Net Zero Emissions (NZE) target. The results are also consistent with the observations of [22] regarding the important role of solar energy and battery storage in improving energy security and reducing fossil fuel dependence in remote island power systems.

4. Conclusion

Based on the LEAP simulation results, Tomia Island has strong potential for the development of a hybrid Solar PV–BESS system to reduce dependence on diesel generation and improve the sustainability of its isolated power system. Although the technical potential of Solar PV reaches 5.243 MWp, the optimal configuration was identified as 2.5 MWp Solar PV integrated with a 4 MWh BESS, achieving a 45% Renewable Fraction.

This configuration reduces diesel fuel consumption from 2,580 kL/year to 1,420 kL/year and lowers CO_2 emissions by approximately 45% while maintaining system reliability. Economically, it delivers the best performance with an NPC of IDR 648.5 billion, an LCOE of IDR 3,383/kWh, and a payback period of 3.23 years.

Overall, the proposed Solar PV–BESS configuration represents the most feasible technical, economic, and environmental solution for Tomia Island, supporting PLN’s diesel reduction program and Indonesia’s transition toward Net Zero Emissions 2060.

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Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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