# Techno-Economic and Grid Study of Hybrid Diesel Power Plant and Solar Power Plant Systems on Simeulue Island

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**Abstract.** This paper aims to conduct a techno-economic and grid analysis of a hybrid Diesel Power Plant and Solar Power Plant system on Simeulue Island. The research focuses on energy analysis and the impact of transitioning from diesel-based generation to solar-based (dedieselization) as a step toward sustainable energy development. Simeulue Island, home to approximately 96,000 residents, is entirely dependent on Diesel Power Plants (PLTD) due to its geographical isolation from Indonesia's main islands. However, the island possesses considerable solar energy potential, offering a viable renewable energy source that can be utilized year-round. Through hybrid system simulations of PLTD and PLTS using PVsyst, Homer, this research will analyze the required energy generation to meet specific load demands at various times. The proposed photovoltaic (PV) system output capacity is 2.5 MW, utilizing 5,000 PV modules. The simulations indicate that this integration can produce approximately 4,349,203 kWh of solar energy, which contributes to a renewable energy penetration rate of 9.94% of the total load annually. From an economic perspective, the integration of solar power into the existing diesel system leads to a notable reduction in the Levelized Cost of Energy (LCOE), which decreases from Rp 4,253/kWh to Rp 3,772/kWh.

**Keywords:** *diesel power plant, solar, hybrid, Simeulue*

## Nomenclature

| | | |
|---|---|---|
| PV | = | Photovoltaic |
| GHG | = | Greenhouse Gas |
| $CO_2$ | = | Carbon Dioxide |
| kW | = | Kilowatt |
| kWh | = | Kilowatt-hour |
| MW | = | Megawatt |
| E | = | Energy generated (kWh) |
| P | = | Power demand or load (kW) |
| H | = | Efficiency of the system (%) |
| Cdiesel | = | Cost of diesel fuel (Rp/liter) |

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| | | |
|---|---|---|
| Csolar | = | Cost of solar system components (Rp/kW) |
| O&M | = | Operating and Maintenance costs (Rp/year) |
| $CO_2$ emission | = | Carbon dioxide emissions (kg $CO_2$) |
| | = | |
| PVsyst Homer | = | Solar simulation software for PV system analysis Hybrid Optimization Model for Energy Resources |
| Dedieselization | = | The process of reducing or replacing diesel energy production with renewable energy sources. |
| Hybrid System | = | An energy system combining multiple power sources, such as diesel and solar, to increase efficiency and reliability. |
| Sustainable Energy | = | Development that meets energy needs while minimizing environmental impact and conserving resources for the future. |
| Renewable Energy | = | Energy generated from natural, inexhaustible sources such as sunlight, wind, or hydro. |
| LCOE | = | Levelized Cost of Electricity |

## 1 Introduction

Global warming is a term that refers to the phenomenon of increasing temperatures on Earth's surface, encompassing the atmosphere, land, and oceans (Siagian, 2023). This phenomenon has accelerated over the past century due to human activities, such as fossil fuel combustion, widespread use of non-recyclable plastics, deforestation, industrial production, and the use of chlorofluorocarbons (CFCs) in various household appliances. These activities have led to ozone layer depletion (the atmospheric layer that absorbs ultraviolet radiation and stabilizes Earth's temperature), rising surface temperatures (including sea temperatures), glacier and polar ice melt, and changes in climate and rainfall patterns. Such environmental changes have resulted in significant adverse effects, including the spread of diseases, loss of biodiversity, species extinction, and ecosystem disruption.

In response, in 2016, 195 countries signed the Paris Agreement, a global commitment to address climate change. The primary goal of the Paris Agreement is to limit the increase in global average temperature to below 2° C, with efforts to keep it as close as possible to 1.5°C (UNFCCC, 2016). Each signatory nation is also required to establish and report its Nationally Determined Contributions (NDCs), or national targets, focusing on reducing greenhouse gas emissions. Indonesia, through its Long-Term Strategy for Low Carbon and Climate Resilience (LTS-LCCR) 2050, has set forth a roadmap to achieve a net-zero emissions target by 2060 or sooner, as outlined in the Enhanced Nationally Determined Contributions of the Republic of Indonesia.

To support the national goal of net-zero emissions by 2060, Indonesia's state-owned electricity company, PT PLN (Persero), has implemented a series of measures under its 2021-2030 Electricity Supply Business Plan (RUPTL). A major initiative within this plan is the Diesel Power Plant Dedieselization Program, which involves several stages: connecting isolated systems to the main grid, converting diesel power plants to gas power plants, constructing new gas power plants, and converting diesel-based power plants to renewable energy power plants in areas where grid interconnection is unfeasible. In addition to long-term goals of achieving net-zero emissions, this program aims to reduce the quantity and costs of imported fuel in the power sector. Converting diesel power plants to renewable energy sources is also seen as a means to improve power generation efficiency, particularly in isolated regions, and to increase supply reliability. Furthermore, this conversion represents PLN's commitment to exploring environmentally friendly energy sources, harnessing local energy potential, and assessing future power consumption needs and development opportunities in these regions. The renewable energy plants and technologies will be tailored to the specific energy potential of each location, including wind power, biomass, ocean currents, geothermal, and solar energy (RUPTL PT PLN, 2020).

## The Case of Simeulue Island

Simeulue Island, located in the Aceh Province, is approximately 150 km off the west coast of Sumatra. Due to its considerable distance from the Sumatra mainland and relatively small population (around 96,000 residents), the island’s electrical system is isolated and relies entirely on diesel-based generation, primarily from two plants: Lasikin and Kampung Aie (Harnita, 2023). To align with the national dedieselization program, Simeulue Island is considered suitable for the conversion of diesel-based generation to renewable energy sources. In 2022, PT PLN initiated a dedieselization program targeting the conversion of approximately 5,200 diesel plants operating across various remote regions in Indonesia, including Simeulue Island (Christian, 2022).

To support this transition on Simeulue, research on the island’s solar energy potential, energy requirements, and the potential environmental impacts of a solar power plant is essential. This research would provide valuable insights into the feasibility and effectiveness of using solar power to meet Simeulue’s energy needs sustainably, aligning with Indonesia's broader renewable energy goals.

## 2 Methodology

This study will begin with the collection of primary and secondary data, including information on the available land area on Simeulue Island, as well as the island's current energy demand. This stage will be followed by gathering solar irradiation data, which will be cross-referenced with records from relevant agencies that measure solar radiation across different regions. The next phase involves running simulations using three software tools to generate outputs that assess how an integrated diesel and solar power system can be optimized to ensure reliable electricity generation for Simeulue Island. During this process, the Levelized Cost of Energy (LCOE) will be calculated, which represents the average cost per unit of electricity generated over the system's lifetime, factoring in capital expenditures, operational costs, and fuel expenses. The LCOE will serve as a deciding factor in determining the most cost-effective configuration for the integrated power system. Figure 1 provides a detailed flowchart of the research process.

### 2.1 Data

**Figure 2** presents a graph illustrating fuel consumption on Simeulue Island from January to May 2024. The figure shows that the monthly diesel fuel usage consistently reaches approximately 1 million liter, with the cost per liter estimated at 11,195 Rupiah

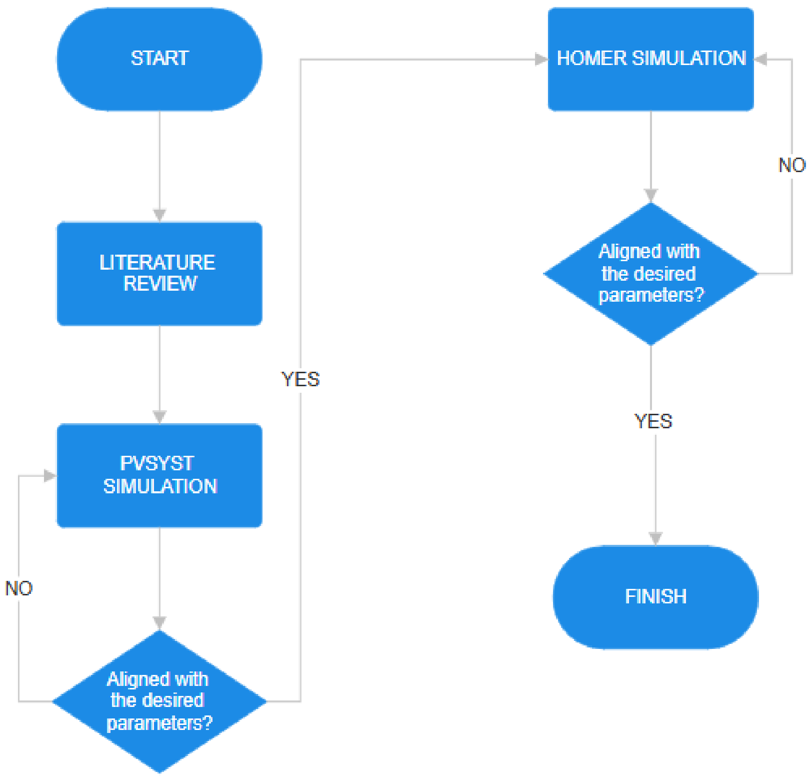


**Figure 1** Modelling Simulation low hart

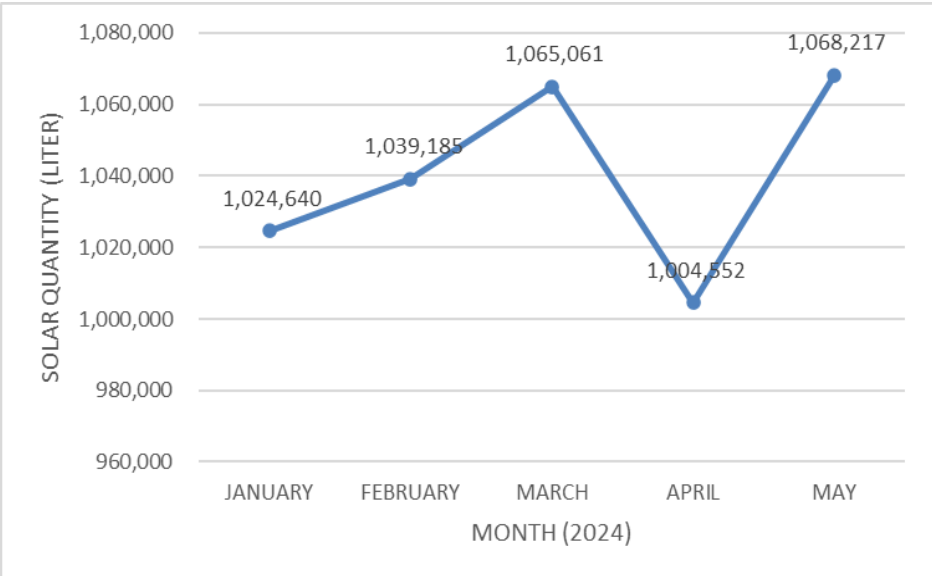


**Figure 2.** Fuel Consumption on Simeulue Island

In **Figure 3**, the electricity usage data for Simeulue Island on February, 2024, is displayed, with a peak load of 6,800 kW and an average usage of 5,000 kW.

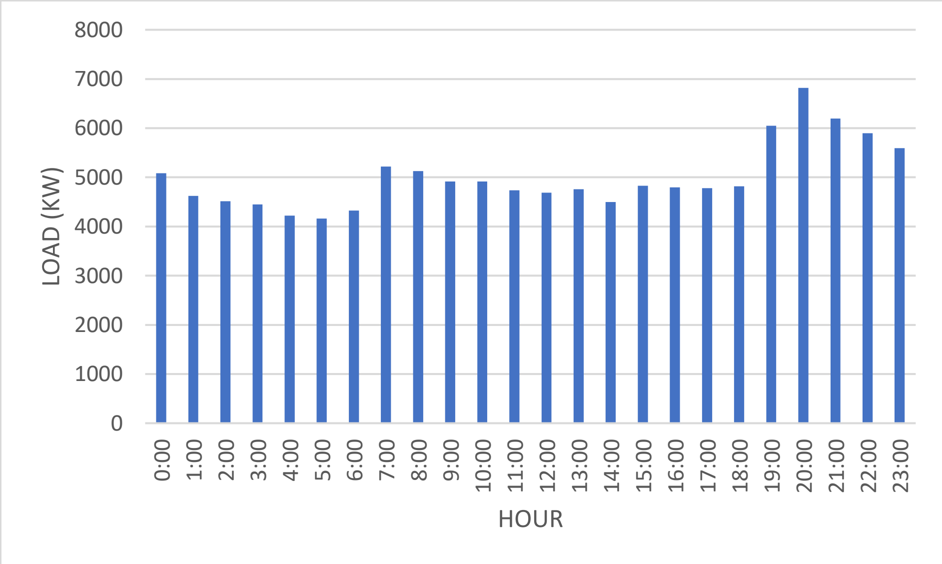


**Figure 3.** Diesel Power Plant Load Profile on Simeulue Island

## 3 Result and Discussion

With a primary constraint of the available land area measuring 12,000 m², the PV system's output capacity is 2.5 MW, requiring a total land area of 11,873 m². The system is composed of 5,000 PV modules arranged into three arrays. The first array consists of 100 strings, each containing 24 modules connected in series, resulting in 10 inverters, each handling 10 strings. The second array comprises 90 strings of 24 modules in series, supported by 9 inverters, each also connected to 10 strings. The third array contains 20 strings of 22 modules, connected to a single inverter. The total output from the inverters amounts to 2 MWAC. The simulation results are presented in Table 1.

Table 1. PVsyst Input& Result

| | |
|---|---|
| Weather Data | Meteonorm 8.1 |
| Module | 5000 units (500 Wp each) |
| Inverter | 20 units (100 kWac each) |
| PV Field Orientation | $11^0$ tilt fixed plane |
| Result | |
| Array Nominal Energy | 3,778,084 kWh/ year |
| Performance Ratio | 0.851 |

The array's nominal energy, shown in Table 1, and the customer load, shown in Figure 2, are the main inputs for the HOMER simulation. Simeulue Island currently uses 12 active diesel generators to supply electricity to customers. The input data for these generators is based on existing diesel generators records from the island. Generator scheduling uses the default "optimized" mode in HOMER, which adjusts operations automatically based on energy demand and the availability of renewable sources. This process is managed using load following and cycle charging methods. Table 2 compares two systems: the current condition without PV and a system with PV integration based on simulations from PVsyst. A notable difference is seen in the Levelized Cost of Energy (LCOE). In the first system, the LCOE is Rp 4,253, whereas in the second scenario, which includes PV, the LCOE is reduced to Rp 3,772, with a renewable energy penetration rate of 9.94%.

Table 2. Comparation Between Various Systems

| Parameter | System 1 | System 2 |
|---|---|---|
| Number of Diesel Generator | 12 | 12 |
| Diesel (kW) | 8,445 | 8,445 |
| PV (kW) | - | 2,500 |
| PV energy (kWh/year) | - | 4,349,203 |
| Inverter (kW) | - | 2,000 |
| LCOE | Rp 4,253 | Rp 3,772 |
| Diesel energy (kWh) | 1.010.381 | 795.077 |
| Diesel fuel (Liters) | 13,934,387 | 12,371,496 |
| Diesel fuel (Liters/hour) | 1,591 | 1,405 |
| RE fraction (%) | 0 | 9.94 |
| $CO_2$ emissions (kg/year) | 36,446,524 | 32,194,494 |
| Economic Metric | | |
| IRR (%) | - | 33 |
| ROI (%) | - | 28 |
| Simple Payback (Tahun) | - | 2.4 |

## 4 Conclusion

The hybrid Diesel Power Plant and Solar Power Plant systems on Simeulue Island reveals significant potential for integrating solar energy into the existing energy framework. With a land area constraint of 12,000 m², the proposed photovoltaic (PV) system output capacity is 2.5 MW, utilizing 5,000 PV modules. The simulations indicate that this integration can produce approximately 4,349,203 kWh of solar energy, which contributes to a renewable energy penetration rate of 9.94% of the total load annually.

From an economic perspective, the integration of solar power into the existing diesel system leads to a notable reduction in the Levelized Cost of Energy (LCOE), which decreases from Rp 4,253 to Rp 3,772. Furthermore, the annual reduction in diesel fuel consumption, from 13,934,387 liters to 12,371,496 liters, results in a decrease in operational costs by approximately Rp 17.5 billion.

## 5 Acknowledgement

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