

## Feasibility Analysis of Converting Diesel Power Plants (PLTD) to Solar Power Plants (PLTS) on Seira Island in Order to Reduce Electricity Supply Costs

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### ABSTRACT

*Seira Island still relies on Diesel Power Plants (PLTD) as its main source of electricity supply, which results in high operating costs, dependence on fossil fuels, and increasing greenhouse gas emissions. This condition highlights the need for more efficient, sustainable, and environmentally friendly alternative power plants. This research aims to analyze the technical and economic feasibility of converting the power generation system from PLTD to Solar Power Plants (PLTS) on Seira Island to reduce electricity supply costs. The research method used is a quantitative descriptive analysis with a feasibility study approach, which includes analyzing electrical energy needs, solar power capacity planning, and an economic feasibility evaluation using Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP) indicators. The data used are secondary data obtained from relevant agencies, technical reports of power plants, and supporting literature. The study results show that converting PLTD to solar power plants can significantly reduce the operational costs of power generation and decrease dependence on diesel fuel. Moreover, the economic analysis demonstrates that the solar power plant project on Seira Island is feasible to implement, with a positive NPV value, an IRR above the benchmark interest rate, and a relatively short investment payback period. Therefore, the conversion from PLTD to solar PV can serve as a strategic solution for providing sustainable and efficient electrical energy in remote island areas.*

**KEYWORDS** *PLTD; PLTS; economic viability; electricity supply costs; Renewable Energy*



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### INTRODUCTION

In Indonesia, Diesel Power Plants (PLTD) are still the mainstay for providing electricity to remote islands. The use of PLTD presents its own challenges, particularly the high operating costs of fuel and the expensive transportation required to reach remote areas (Techno-Economic Analysis of Diesel/Wind/PV/Battery Hybrid Energy System for Androth Island, 2021). This situation increases the subsidy burden borne by the government to maintain the affordability of electricity prices (Naderipour et al., 2022; Pambudi et al., 2023; Pascasio et al., 2021; Ramadan et al., 2024). (The use of PLTD also negatively impacts the environment as it contributes to rising carbon emissions Agyekum et al., 2021; Asbow et al., 2024).

Indonesia is committed to reducing carbon emissions to support the Net Zero Emission (NZE) target by 2060. Fossil fuel-based PLTDs make a significant contribution to greenhouse gas emissions (Nabila et al., 2024a), making them inconsistent with the government's clean energy transition efforts. To reduce dependence on PLTD, one program implemented is dedieselization, which aims to replace diesel-fueled plants with renewable energy sources such as Solar Power Plants (PLTS). This initiative not only supports efforts to lower carbon emissions but also has the potential to reduce the long-term burden of energy subsidies.

Within the National Energy Policy (KEN), the government has set a target for the renewable energy mix to reach 21.0% by 2030 and to reduce the fossil energy share to 52%

by 2044 at the latest (Presidential Decree No. 79 of 2014). Achieving this target poses a major challenge, given that the current share of renewable energy in Indonesia's power plants has only reached 15% (Ministry of Energy and Mineral Resources, 2024).

The electricity supply to Indonesia's islands remains heavily dependent on PLTD. PLTD has long been a solution for providing electricity in remote and isolated areas due to its ease of installation and operational flexibility. However, dependence on PLTD brings several challenges, especially the high operational costs caused by fossil fuel use and the negative environmental impacts such as carbon emissions and air pollution (Chamdareno & Hilal, 2018).

One of the islands that still uses PLTD as its main source of electricity is Seira Island. The island is located in a remote region of Indonesia, with limited access to the main power grid. Challenging geographical conditions make fuel distribution for PLTD expensive and inefficient, resulting in very high electricity provision costs on Seira Island (Budi Ariyadi & Purwanto, 2024; Hanif et al., 2020; Kumar et al., 2022).

To address these issues, converting PLTD to Solar Power Plants (PLTS) is a potential solution (Renewable Energy for Remote Communities: A Guidebook for Off-Grid Projects, n.d.). The use of solar energy is expected to lower electricity provision costs in the long term, reduce dependence on fossil fuels, and improve the reliability of the electricity system.

Indonesia possesses vast and diverse renewable energy potential. The country's abundant natural resources—ranging from solar energy, wind, and biomass to hydropower—offer great opportunities. According to data from the Directorate General of New and Renewable Energy, Ministry of Energy and Mineral Resources (EMR), Indonesia has substantial solar energy potential, with an exploitable area equivalent to 3,294 MW, of which only 0.01% has been utilized (Ministry of Energy and Mineral Resources, 2024). With further development, solar energy holds strong prospects to replace fossil fuels (Silalahi et al., 2021).

Several studies have explored the conversion of PLTD to solar power as a clean energy transition solution while ensuring a 24-hour electricity supply (Chamdareno & Hilal, 2018; Techno-Economic Analysis of Diesel/Wind/PV/Battery Hybrid Energy System for Androth Island, 2021). However, most existing research still focuses on technical aspects, without conducting extensive financial analyses emphasizing the optimization of solar and battery capacities to reduce electricity production costs and environmental impacts—particularly in small, remote archipelagic areas such as Seira Island.

Based on this research gap, the present study is not merely replicative but introduces a novelty through a holistic approach addressing system efficiency, supply reliability, and long-term economic analysis for providing 24-hour electricity based on solar and battery systems in remote areas, with Seira Island as the case study. The objectives of this study are to analyze the economic feasibility of converting Diesel Power Plants (PLTD) into Solar Power Plants (PLTS) on Seira Island; to determine the required solar capacity needed to replace PLTD; to evaluate the economic feasibility of the conversion; and to identify the optimal solar capacity for implementation. Additionally, the study aims to assess potential reductions in electricity supply costs and the environmental impacts resulting from using solar PV compared to PLTD.

This research is expected to contribute to scientific development in the field of renewable energy, particularly concerning the conversion of diesel-based to solar-based

power generation systems. It may also serve as a reference for further studies on the application of renewable energy technologies in remote areas..

## METHOD

This study uses a qualitative approach. This approach was chosen because it emphasizes objective and numerical analysis of various aspects, such as technical, economic, and environmental in the conversion of PLTD to solar power plants on Seira Island. A feasibility study was conducted to determine whether the project could be implemented taking into account the data obtained and systematically analyzed.

This study also uses a case study approach to in-depth study the conversion of PLTD to solar power plants on Seira Island. The stages of this case study research are adapted from the case research model developed by Yin (2018), as follows:

1. Design Phase This stage formulates specific research problems related to the feasibility of converting PLTD to solar power plants on Seira Island. The researcher also determines the unit of analysis, data collection method, economic indicators, and financial analysis framework (Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PP), and Levelized Cost of Electricity (LCOE).
2. Preparation Phase The preparation of the research protocol is carried out to ensure that the data collection process runs systematically. This stage involves coordination with related parties, such as PT PLN (Persero), the Ministry of Energy and Mineral Resources to obtain technical data and energy policies.
3. Data Collection Phase Secondary data related to the conversion of PLTD to solar power plants on Seira Island was collected through data requests to the Ministry of Energy and Mineral Resources and PT PLN (Persero).
4. Analysis Phase The analysis starts from the preparation of projections of future electricity supply needs with load forecasting to obtaining solar PV capacity and batteries to replace the role of PLTD. In addition, it also analyzes the economics of solar PV costs with a financial model that takes into account using indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PP).

The cost of solar power plants will be compared with the cost of PLTD, to then find the optimal point of solar PV capacity to replace PLTD ( $BPP_{Hybrid} = \text{initial } BPP_{PLTD}$ ). In addition, the potential for cost reduction ( $BPP_{PLTD} - BPP_{hybrid}$ ) and environmental impact through the reduction of carbon emissions ( $PLTD \text{ Emissions} - Hybrid \text{ Emissions}$ ) will also be analyzed.

5. Validation and Reporting Phase The results of the analysis can produce data-based conclusions that can be empirically tested from an economic perspective. From this conclusion, it provides an objective overview and strategic recommendations for the Government and PT PLN (Persero) regarding the optimization of the conversion of solar power plants to PLTD on Seira Island by considering the impact of the cost of electricity supply and environmental impact

### Research Instruments

The research instruments used to obtain secondary data through relevant data requests include electricity needs, cost of electricity supply, investment and operational costs of solar PV. The data request guidelines are an instrument to dig deeper information from

stakeholders, such as officials of the Ministry of Energy and Mineral Resources and employees of PT PLN (Persero). The data request was carried out in a semi-structured manner to provide flexibility in exploring respondents' perspectives related to technical, economic, and regulatory aspects related to the implementation of solar PV.

Meanwhile, to support the completeness of the analysis and validity of the data, this study also uses a document review instrument. The documents analyzed include reports from PT PLN (Persero), government policies related to renewable energy, and the results of previous studies on energy conversion in remote areas. In addition, the researcher also utilizes publications from scientific journals, academic reference books, and documents from related institutions that contain information on the investment and operational costs of solar PV, technological efficiency, and supporting regulations. The combination is expected to result in an in-depth understanding of the feasibility of the PLTD to Solar Power Plant conversion project on Seira Island.

In analyzing the need for electricity supply in the future (20 years) with load growth forecasting. Based on the need for electricity, the need for solar power capacity and batteries will be obtained to replace the role of PLTD around the clock or 24 hours on.

**Table 1.** Analytical Indicators

No.	Variable	Concept	Indicators/Formulas	Refereces
1	NPV ( <i>Net Present Value</i> )	The difference between the present value of cash inflows and the present value of cash outflows over the life of the project	$NPV = \sum Ct / (1+r)^t - C0$ with: Ct = cash flow for the year t, r = discount rate, C0 = initial investment	Ross et al. (2013)
2	IRR ( <i>Internal Rate of Return</i> )	The discount rate that makes NPV equal to zero. Demonstrate the efficiency of the return on investment.	$\sum Ct / (1+IRR)^t = C0$ Ct = cash flow for the year t, C0 = initial investment	Ross et al. (2013)
3	PP ( <i>Payback Period</i> )	The period of time it takes to return the initial investment from the cash flow generated by the project.	$PP = \text{Initial Investment} / \text{Annual Cash Flow}$	Ross et al. (2013)
4	Levelized Cost of Electricity (LCOE)	The average cost per unit of electricity (USD/kWh or USD/MWh) generated by the plant over the life of the project, including investment, operation & maintenance, fuel, and capital costs	$LCOE = \frac{\sum_{t=0}^n \frac{I_t + O_t + F_t}{(1+r)^t}}{\sum_{t=0}^n \frac{E_t}{(1+r)^t}}$ with a caption: <ul style="list-style-type: none"> <li>• It = capital cost in the year t</li> <li>• O = operating and maintenance costs in the year t</li> <li>• Ft = fuel cost in the t year (if any)</li> <li>• Et = electrical energy generated in the year t</li> <li>• R = discount rate</li> <li>• n = project life (years)</li> </ul>	Ross et al. (2013)

Source: Ross et al. (2013)

Based on the financial model, a Levelized Cost of Electricity (LCOE) or solar PV cost will be obtained. Furthermore, the analysis is carried out to determine the optimal solar power plant capacity in order to maximize the cost of supply savings with Cost Optimization Theory where the optimal capacity is the capacity that minimizes the total cost of the system or reaches a break-even between two alternative technologies (BPPHybrid = initial BPP PLTD).

The cost of solar power will be compared with the cost of PLTD, to then find an optimal point that can be done in order to reduce the BPP of electric power. In addition, the potential for cost reduction (BPP PLTD - BPP hybrid) and environmental impact through the reduction of carbon emissions (PLTD Emissions - Hybrid Emissions) will also be analyzed.

### Data Analysis Methods

The data analysis method in this study uses a qualitative approach related to the conversion of PLTD to solar PV. To determine the need for solar power capacity to replace PLTD on Seira Island, it was first analyzed to analyze the need for electricity supply in the future (20 years) with load growth forecasting. Furthermore, based on these needs, the capacity needs of solar PV are calculated with the formula as:

$$P_{PLTS} = \frac{E_{target}}{CF_{PLTS} \times 8760}$$

where:

$E_{target}$  = PLTD energy to be replaced (kWh/year)

$P_{PLTS}$  = installed capacity of solar power plants (kWp)

$CF_{PLTS}$  = capacity factor PLTS

In addition, to ensure a 24-hour electricity supply, a battery with a capacity according to the formula is needed as:

$$C_{bat} = \frac{E_{load} \times N_{aut}}{DOD \times \eta_{bat}}$$

where:

$C_{bat}$  = battery capacity (kWh)

$E_{load}$  = daily energy requirement (kWh/day)

$N_{aut}$  = autonomy day

$DOD$  = depth of discharge

Based on the capacity of solar power plants and batteries that will replace PLTD, a feasibility analysis of the solar power plant project on Seira Island was carried out through financial modeling based on projected cash flows over the operational life of the solar power project. This model compiles a cash flow simulation taking into account the initial investment, operating and maintenance costs, electricity production during the operating life. The analysis indicators used include Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PP). Through this approach, the research can measure the amount of production cost per kWh of solar power plants (Levelized Cost of Electricity / LCOE).

In determining the optimal capacity of solar power plants and batteries, namely by minimizing the total cost of the system or reaching the break-even point of production costs

between two alternative technologies (BPPHybrid = initial BPP PLTD). Furthermore, the cost of solar PV will be compared with the cost of PLTD, to then find the optimal point that can be done. In addition, the potential for cost reduction (BPP PLTD - BPP hybrid) and environmental impact through the reduction of carbon emissions (PLTD Emissions - Hybrid Emissions) will also be analyzed. This process allows researchers to draw conclusions and provide more in-depth and objective recommendations that can be made in the conversion of PLTD to solar power plants on Seira Island.

## **RESULT AND DISCUSSION**

### **PT Perusahaan Listrik Negara (Persero)**

PT Perusahaan Listrik Negara (Persero) or PT PLN (Persero) is a state-owned enterprise (SOE) assigned by the government to provide electricity for the public interest in Indonesia. The company plays an essential role in the national electricity system, being responsible for electricity provision from generation, transmission, and distribution to the sale of electricity to customers. The assignment given to PT PLN (Persero) aligns with the mandate of Law Number 30 of 2009 concerning Electricity, which emphasizes that the state is responsible for ensuring the sustainable availability of electricity to support economic development and community welfare.

As the largest electricity provider in Indonesia, PT PLN (Persero) serves more than 92 million customers (source: Ministry of Energy and Mineral Resources), including those in remote areas and islands. In carrying out its function, PT PLN (Persero) not only focuses on the business aspect as a company but also fulfills its role in the Public Service Obligation (PSO)—ensuring that electricity tariffs remain affordable for the public through government subsidy support.

PT PLN (Persero) often faces challenges in providing electricity to remote and isolated areas, where the electricity supply is highly dependent on fossil fuel-based plants such as PLTD, which involve high electricity supply costs. To address these challenges, PT PLN (Persero) continues to promote energy sector transformation through the development of New and Renewable Energy (NRE)-based power plants as part of the national energy transition strategy. This effort aligns with the Indonesian government's commitment to increasing the renewable energy mix and reducing carbon emissions.

One of the remote areas where electricity is supplied by PT PLN (Persero) is Seira Island, located in Maluku Province. The island is part of the Tanimbar Islands, an archipelago characterized by remote geographical conditions and predominantly coastal areas. These circumstances make the development of basic infrastructure, including electricity, face relatively high logistical and cost challenges compared to areas connected to the mainland electricity grid.



**Figure 1. PLTD Location**  
Source : PT PLN (Persero)

On Siera Island, PT PLN (Persero) must provide electricity to the community of around 1,519 customers, dominated by households with a total installed power of 1,454,350 VA and electricity consumption of 311,027 kWh/month (July 2025 usage) (table 4.1). PT PLN (Persero) has targeted electricity sales growth of around 3%/year, so good system planning is needed to meet long-term electricity needs.

**Table 2. Customer on Siera Island**

Tariff Classes	Number of Customers	Power (VA)	July 2025 Electricity Sales (kWh)
Social	38	111.150	6.687
Household	1.451	1.243.900	298.124
Business	22	84.100	5.441
Industry	0	0	0
Audience	7	9.700	517
Specialized Services	1	5.500	258
<b>Quantity</b>	<b>1.519</b>	<b>1.454.350</b>	<b>311.027</b>

Source: PT PLN (Persero) (2025)

In order to meet the electrical energy needs of the people on Siera Island, which totals around 1,519 customers, PT PLN (Persero) relies on PLTD as the main source of generation. Dependence on PLTD generally occurs in archipelagic areas and isolated areas that have not been reached by the interconnection network of the electricity system. Therefore, the existence of PLTD has a strategic role in ensuring the continuity of electricity supply and supporting the social and economic activities of the local community.

However, some PLTD units operating on Siera Island have been used for a relatively long period of time, even exceeding 20 years of operation (table 4.2). This condition has the potential to cause various technical and economic consequences, such as a decrease in the level of machine efficiency, an increased risk of operational interruptions, and an increase in the frequency of maintenance and repair activities. In addition, the increasing age of the plant also has implications for increasing operational costs, especially due to fuel consumption which tends to be more wasteful.

**Table 3. List of Siera Island PLTD Plants**

Brand	Year	Mounting Power	Capable Power (kW)
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		(kW)	
<b>DEUTZ BF6M1015CP</b>	2023	250	200
<b>MAN D2866LE201</b>	2000	250	200
<b>VOLVO TAD1342GE</b>	2020	200	160
<b>DEUTZ BF6M1015CP</b>	2003	250	160
<b>Total</b>		<b>950</b>	<b>720</b>

Source: PT PLN (Persero) (2025)

Considering that electricity supply is still dominated by PLTD, one of the largest cost components in the electricity supply on Seira Island is fuel oil (BBM), particularly diesel. Challenges arise in electricity production, as diesel fuel must be transported from outside the island over a considerable distance. This issue was also identified in previous research on Kawaluso Island (Ilham Amba & Dalimi, 2023a), which found that the BPP PLTD on Kawaluso Island was dominated by fuel costs and faced potential risks from disrupted fuel supply.

With diesel prices being relatively high, coupled with very expensive transportation costs, the fuel cost burden becomes the dominant component in the basic cost structure of electricity supply (BPP). Based on data from PT PLN (Persero), the BPP of electricity in PLTD Seira as of August 2025 was IDR 6,699/kWh, far above the national average of only IDR 1,243/kWh.

Beyond cost concerns, full dependence on diesel also creates vulnerability in the energy supply. Adverse weather conditions, a limited shipping fleet, or other distribution disruptions can halt diesel deliveries, threatening the reliability of electricity on Seira Island. This finding aligns with previous research on Karimunjawa Island (Hiron et al., 2021), which confirmed that PLTD-based systems are highly susceptible to fuel supply disruptions due to weather and logistical constraints. Moreover, diesel combustion produces exhaust gas emissions and noise pollution, negatively impacting the environment and the comfort of nearby communities.

Seira Island has significant potential for solar energy, as the level of solar radiation in the Maluku region is relatively high throughout the year. According to data from the Global Solar Atlas (GSA) for Indonesia, the national average solar radiation intensity (GHI) ranges from 4.5–5.6 kWh/m<sup>2</sup>/day. In the southern part of Maluku, including Seira Island—located in the Tanimbar Islands—the radiation intensity is quite strong, around 5.0–5.4 kWh/m<sup>2</sup>/day, equivalent to potential solar energy of 1,700–1,900 kWh/m<sup>2</sup>/year. These conditions present great opportunities for utilizing solar power plants as a primary energy source to support electricity availability for local communities.

This situation reinforces the high urgency for Seira Island to transition from a fuel-based PLTD system to a cleaner and more sustainable solar PV system. By harnessing its abundant solar energy potential and incorporating energy storage technology, the community's electricity needs can be met more efficiently, affordably, and sustainably. Such a transition would also minimize dependence on long-distance, high-cost diesel shipments while strengthening energy security in remote island regions.

### **The Need for Solar Power for Long-Term Electricity Supply**

The conversion of PLTD to solar power plants on Seira Island requires careful electrical system planning, especially in anticipation of long-term electrical energy needs. This planning aims to ensure that the installed solar capacity is able to meet the growth of the load in a Feasibility Analysis of Converting Diesel Power Plants (PLTD) to Solar Power Plants (PLTS) on Seira Island in Order to Reduce Electricity Supply Costs

sustainable manner without causing the risk of supply deficit in the future. Therefore, the preparation of electricity demand projections is an important stage in determining the optimal capacity of solar PV.

The forecast of the electricity demand of Siera Island is carried out using an exponential growth model, which is generally applied in energy planning to describe the increase in electricity consumption due to population growth, economic activity, and an increase in the electrification ratio. Formula used:

$$E_t = E_0(1 + g)^t$$

where:

$E_t$  = t-year electrical energy requirement (kWh)

$E_0$  = base year electrical energy requirement (kWh)

$g$  = Growth rate of electrical load (%/year)

$t$  = planning period (years)

The  $E_t$  value is the basis for determining the capacity of solar power plants to replace PLTD.

Based on data obtained from PT PLN (Persero), the initial consumption (in 2025) is 311,027 kWh/month or equivalent to 3,732,324 kWh/year ( $E_0$ ). For annual growth, it is targeted to grow by 3.1% per year ( $g$ ) with a planned period of 20 years ( $t$ ) following the operating life of the plant. Based on this data, the following were obtained:

$$E_t = E_0(1 + g)^t$$

$$\text{And} = 3,732,324 \text{ kWh} (1 + 3.1\%)^{20}$$

$$\text{And} = 6,873,100 \text{ kWh}$$

Based on the results of the calculation above, the electricity demand at the end of the planning period is estimated to reach around 6,873,100 kWh per year. These results show a significant increase in energy demand compared to the initial conditions, so it is an important basis for determining the planned solar power plant capacity to be able to ensure the sufficiency of electricity supply in a sustainable manner on Siera Island.

To answer the need for electrical energy on Siera Island which reaches around 6,873,100 kWh per year in the long term continuously for 24 hours, a power generation system is needed that not only relies on solar PV, but is also equipped with a Battery Energy Storage System (BESS) so that electricity supply remains available 24 hours a day. The configuration of the PLTS+BESS system is in accordance with the results of a study (Mahmoudi et al., 2023) in Algeria which shows that a combination of solar PV systems with battery utilization can provide electricity needs for 24 hours.

To meet the needs of 6,873,100 kWh per year ( $E_{\text{target}}$ ), the amount of solar PV capacity can be calculated with the following formula:

$$P_{PLTS} = \frac{E_{\text{target}}}{CF_{PLTS} \times 8760}$$

where:

$E_{\text{target}}$  = PLTD energy to be replaced (kWh/year)

$P_{\text{PLTS}}$  = installed capacity of solar power plants (kWp)

CF\_PLTS = capacity factor PLTS

The capacity factor is an important technical parameter in solar PV planning because it reflects the ratio of the actual electrical energy generated to the maximum energy that can be produced if the plant is operating at full capacity all the time. Thus, the capacity factor value serves as an indicator of system performance as well as a basis for realistically estimating energy output. Referring to data from the Ministry of Energy and Mineral Resources (EMR), the calculation of solar power plant capacity for remote areas or isolated systems generally uses the assumption of a capacity factor of around 11%, which has taken into account solar irradiation conditions, technological efficiency, and potential losses in the system.

This finding is also strengthened by an empirical study on the performance of solar power plants in Indonesia which shows that the capacity factor of  $\pm 11\%$  is the actual value based on the results of the operation of the photovoltaic system. Budiman Kamil et al. (2022) emphasized that capacity factor-based performance evaluation is more representative because it is directly oriented to the energy produced by the system. Therefore, the use of a capacity factor of 11% in this study is considered relevant and conservative to produce a more accurate estimate of solar PV capacity, especially in supporting the plan to convert PLTD to solar power plants in the electricity system of Seira Island. Based on these assumptions, the amount of solar PV capacity is obtained, namely

$$PPLTS = E_{target} / (CF_{PLTS} \times 8760)$$

$$PPLTS = 6.873.100 \text{ kWh} / (11\% \times 8760)$$

$$PPLTS = 6.873.100 \text{ kWh} / (11\% \times 8760)$$

$$PPLTS = 7.132,73 \text{ kWp}$$

Based on the results of the calculation above, the solar power plant capacity was obtained of 7,132.73 kWp. To guarantee electricity supply on Seira Island for 20 years.

To meet the needs of 24 hours, batteries are needed for the provision of electricity in conditions where there is no sun or at night. The battery capacity is formulated as:

$$C_{bat} = \frac{E_{load} \times N_{aut}}{DOD \times \eta_{bat}}$$

where:

$C_{bat}$  = battery capacity (kWh)

$E_{load}$  = daily energy requirement (kWh/day)

$N_{aut}$  = autonomy day

DOD = depth of discharge

$\eta_{bat}$  = battery efficiency

The daily electrical energy requirement is calculated at 18,830 kWh/day ( $E_{(load)}$ ), which is obtained from the total annual energy requirement of 6,873,100 kWh divided by the number of days in a year (365 days).

For the autonomy period of  $N_{aut}$  days, based on data from the Ministry of Energy and Mineral Resources (EMR) it is assumed for 2 days. Autonomy days are the duration of energy reserves that must be available in the battery system to ensure the continuity of electricity supply when primary sources, such as solar PV, cannot operate optimally due to solar

radiation limitations or weather disturbances. The assumption that the use of autonomy days is still relevant and conservative for electricity systems in remote areas, and is strengthened by research by Meyer et al. (2022) who stated that the need for autonomy days in stand-alone photovoltaic systems is generally in the range of 1–3 days, depending on the expected level of system reliability. Therefore, the selection of these values is considered to be able to increase the reliability of electricity supply while maintaining a balance between the technical and economic aspects of the system.

The depth of discharge (DoD) parameter to be used is based on data from the Ministry of Energy and Mineral Resources (ESDM) in the planning of the solar PV battery system of 80%. DoD is the percentage of a battery's usable energy capacity compared to its total capacity. The determination of DoD values is a crucial aspect in the design of energy storage systems because it has a direct effect on battery life, system reliability, and life cycle cost. Too high a DoD usage has the potential to accelerate battery degradation, while too low a value can lead to a larger and less economical battery capacity requirement.

The DoD assumption of 80% is also supported by various international studies stating that lithium-ion batteries, which are currently the dominant technology in Battery Energy Storage Systems (BESS), are generally designed to operate in the DoD range of 70–90% (Cole et al., 2019). In addition, the International Renewable Energy Agency (IRENA, 2017) emphasized that the DoD selection of around 80% is a conservative approach that is widely applied to the planning of utility-scale energy storage systems and mini-grids, especially to improve the reliability of electricity supply in remote areas. Thus, the use of DoD of 80% can be considered realistic because it not only refers to national guidelines, but is also in line with best practices in the planning of battery-based solar PV systems.

Battery efficiency ( $\eta_{bat}$ ) is defined as the ratio between the electrical energy that can be released by the battery during the discharge process with the electrical energy absorbed at the time of charging. This parameter reflects the amount of internal energy loss that occurs due to electrochemical processes, power conversion, and battery operating conditions. The battery efficiency parameter ( $\eta_{bat}$ ) that will be used is based on data from the Ministry of Energy and Mineral Resources (EMR) in the planning of the solar PV battery system by 90%. These parameters are still vulnerable to the round-trip efficiency of modern batteries, especially lithium-ion batteries which are in the range of 85-95% depending on technology and operating conditions (IRENA, 2017).

With the parameters mentioned above, it can be calculated the amount of battery capacity that will be installed with solar PV with the following calculations:

$$C_{bat} = (E_{load} \times N_{aut}) / (DOD \times \eta_{bat})$$

$$C_{bat} = (18.830 \times 2) / (0.8 \times 0.90)$$

$$C_{bat} = 37.660 / 0.72$$

$$C_{bat} = 52,305.56 \text{ kWh}$$

Based on the results of the analysis of the calculation of electricity demand for 24 hours by considering the projected growth of electricity consumption in the future community on Siera Island of 6,873,100 kWh/year, it can be concluded that the conversion of PLTD to solar power plants is feasible. To optimally meet these energy needs, a solar power plant capacity of 7,132.73 kWp is needed supported by energy storage in the form of a battery with a

capacity of 52,305.56 kWh, so that the continuity of electricity supply can be maintained at all times.

### **Calculation of the Economic Feasibility of Solar Power Plants in Comparison with PLTD**

The analysis of the economic feasibility of solar projects in this study is an essential component of financial management, particularly in long-term investment decision-making. Investment in a solar project is not only related to the initial capital required but also to the fundamental question of the project's long-term financial viability. Therefore, investment decisions must take into account potential risks, the expected rate of return, and the project's ability to generate future cash flows. This aligns with the opinion of Riyanto (1990), who emphasizes that investment decisions should be based on the investment's capacity to provide sustainable economic benefits.

Furthermore, Djarwanto (1993) explains that capital budgeting is the process of planning and evaluating investments in fixed assets whose benefits extend beyond one accounting period. In the context of a solar PV project, the concept of capital budgeting serves as a relevant tool for assessing overall investment feasibility, as such projects are designed for long-term operation. Through this approach, all costs and benefits incurred throughout the project's life cycle can be systematically analyzed. The financial feasibility assessment is performed using indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP)—each providing an overview of economic value creation, investment return rate, and the time required to recover the initial capital.

The cost structure of a solar power plant project generally consists of initial investment costs (Capital Expenditure / Capex) and operating and maintenance costs (Operational Expenditure / Opex). Capex represents the largest cost component, incurred during the project's development stage, and reflects the plant's readiness for long-term operation. In solar PV projects, Capex includes the procurement of solar modules, inverters, mounting systems, electrical and protection systems, civil works, installation and construction activities, as well as engineering and project management costs. To meet Seira Island's requirement for a 24-hour electricity supply, the solar power plant system will be equipped with a Battery Energy Storage System (BESS) and supporting infrastructure, including a battery management system, cooling units, and safety devices.

According to the latest renewable energy technology cost study by the International Renewable Energy Agency (IRENA, 2024), the current cost of solar power systems is approximately 691 USD/kWp, while the cost of Battery Energy Storage Systems (BESS) is around 192 USD/kWh. These values indicate a significant downward trend over recent years, driven by the expansion of global production capacity, improved supply chain efficiency, and advances in battery manufacturing technology.

In addition to investment costs (Capex), the cost structure also includes Operational Expenditure (Opex), which covers recurring expenses required to ensure consistent operation throughout the plant's technical life. For solar PV, Opex consists of maintenance of solar modules and inverters, panel cleaning, minor component replacement, system performance monitoring, and operational management. Meanwhile, in the Battery Energy Storage System (BESS), Opex comprises battery maintenance, operation of the battery management and cooling systems, safety inspections, and costs related to managing battery capacity. Feasibility Analysis of Converting Diesel Power Plants (PLTD) to Solar Power Plants (PLTS) on Seira Island in Order to Reduce Electricity Supply Costs

degradation. Referring to the renewable energy technology cost study (IRENA, 2024), the Opex cost of PLTS is 15 USD/kWp per year, while the Opex for the BESS system is 5 USD/kWh per year. Based on these data, the following information was obtained:

**Table 4.** Capex and Opex PLTS+ BESS

Uraian	Biaya per Unit		(kWp/kWh)	Total Biaya	
1. Capex PLTS	691	USD/kWp	7.132,73	USD	4.928.717
2. Capex BESS	192	USD/kWh	52.306,70	USD	10.042.886
			<b>Jumlah</b>	<b>USD</b>	<b>14.971.603</b>
1. OPEX PLTS	15,00	USD/kWp	7.132,73	\$ /yr	106.990,97
2. OPEX BESS	5,00	USD/kWh	52.306,70	\$ /yr	261.533,49
			<b>Jumlah</b>	<b>USD</b>	<b>368.524,46</b>

Source: IRENA (2024) and author's analysis

Based on the Capex and Opex, the results of the calculation of economic feasibility show that the solar power project with a selling price of electricity or BPP of electricity is 55.26 cUSD/kWh (Rp9,117.90/kWh). With this price, the results of the analysis show that the total cumulative net cash flow during the project period (20 years) reached USD 41,506,873.11, with a cumulative net profit of USD 24,373,744.63. The project's Net Present Value (NPV) was recorded at USD 9,118,149, which is a positive value. This positive NPV indicates that the present value of the economic benefits generated by the project is greater than the total investment cost, so that financially this solar PV project is able to create economic added value so that it is feasible to be developed. Several studies have been conducted previously that the feasibility of solar PV projects in the archipelago must have a positive NPV (Utami & Mulyana, 2024).

**Table 5.** Seira Island PLTS+BESS Qualification Ceremony

Tahun	Produksi (MWh)	Biaya (USD/kWh)	Produksi (MWh)	OPEx (USD)	Biaya (Rp/kWh)	Biaya (USD)	Biaya (USD)	Biaya (USD)	Cash Flow (USD)
0									-8.296.613,00
1	3.840.000,00	55,30	3.128.418	188.524,80	534.899,11	178.500	360.983,34	3.505.586,00	6.296.613,00
2	3.887.204,00	55,30	3.180.208	188.524,80	471.803,50	178.500	452.713,00	3.558.000,00	3.558.000,00
3	4.000.000,00	55,30	3.298.201	188.524,80	472.204,09	178.500	542.950,17	3.605.577,20	3.605.577,20
4	4.127.188,00	55,30	3.398.078	188.524,80	393.884,28	178.500	624.845,82	3.658.026,30	3.658.026,30
5	4.267.831,00	55,30	3.483.653	188.524,80	334.483,67	178.500	708.327,38	3.712.713,20	3.712.713,20
6	4.420.203,00	55,30	3.571.082	188.524,80	282.803,09	178.500	823.488,38	3.768.375,81	3.768.375,81
7	4.583.574,00	55,30	3.661.362	188.524,80	239.823,48	178.500	928.391,41	3.825.333,41	3.825.333,41
8	4.754.943,75	55,30	3.753.053	188.524,80	217.261,63	178.500	1.018.876,84	3.883.541,17	3.883.541,17
9	4.932.553,00	55,30	3.754,677	188.524,80	194.881,22	178.500	1.118.120,57	3.945.750,60	3.945.750,60
10	5.116.643,00	55,30	3.758.252	188.524,80	172.480,81	178.500	1.221.959,27	4.009.875,80	4.009.875,80
11	5.307.463,18	55,30	3.761.008	188.524,80		178.500	1.328.369,88	4.074.648,12	4.074.648,12
12	5.505.198,00	55,30	3.763.088	188.524,80		178.500	1.383.438,80	4.142.038,80	4.142.038,80
13	5.689.828,28	55,30	3.765.278	188.524,80		178.500	1.487.438,39	4.211.308,79	4.211.308,79
14	5.772.295,00	55,30	3.767.262	188.524,80		178.500	1.533.545,76	4.280.522,52	4.280.522,52
15	5.860.989,24	55,30	3.769.060	188.524,80		178.500	1.602.452,87	4.358.645,80	4.358.645,80
16	5.955.385,00	55,30	3.771.487	188.524,80		178.500	1.660.273,80	4.435.855,61	4.435.855,61
17	6.071.879,28	55,30	3.773.673	188.524,80		178.500	1.760.429,88	4.512.008,12	4.512.008,12
18	6.188.984,20	55,30	3.775.138	188.524,80		178.500	1.842.650,84	4.588.880,61	4.588.880,61
19	6.306.942,00	55,30	3.776.873	188.524,80		178.500	1.928.277,81	4.674.800,79	4.674.800,79
20	6.427.338,00	55,30	3.778.075	188.524,80		178.500	2.018.727,70	4.758.307,80	4.758.307,80
	104.469.137,50		1.776.486,34	3.861.263,80	14.971.603,28		14.971.603,28	41.506.873,11	41.506.873,11
									NPV
									9.118.149
									IRR Present
									9,00%
									WACC
									4,09%
									Payback Period
									8
									Simple Payback Period
									7,8
									Payback (kWh)
									8.117.80

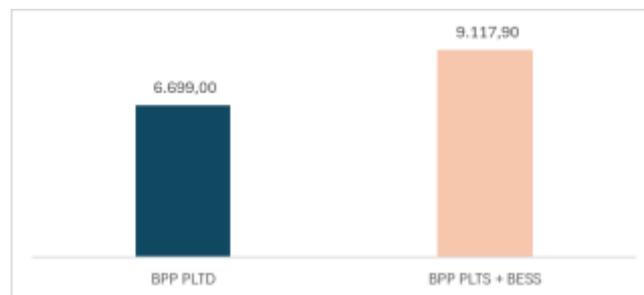
Source: Author's analysis (2025)

Furthermore, the results of the calculation of the project's Internal Rate of Return (IRR) show a value of 9.00%, which is higher than the Weighted Average Cost of Capital (WACC) of 4.09%. This condition confirms that the project's internal rate of return exceeds the capital cost that must be incurred, so that the project is considered financially viable. The significant difference between IRR and WACC also reflects an adequate margin of safety, so that the project is relatively resilient to changes in cost and revenue assumptions within a certain limit.

In the previous study (Garces-Palacios et al., 2024), for the calculation of the feasibility of solar power plants + BESS in the Galapagos Islands, an IRR value of above 9% was given.

Viewed from the aspect of the Payback Period, the results of the financial analysis for the Seira Island solar power plant have a Payback Period value of 9 years. This value shows that the initial investment can be returned in a relatively short time when compared to the economic life of the plant of 20 years. With a payback period shorter than half the economic life of the system, the project still has a long enough operational period to generate net profits and increase the economic value of the investment. So that economically, the Seira Island solar power plant project is feasible to be developed.

Overall, the results of the analysis of NPV, IRR, and Payback Period of the solar power plant project on Seira Island are economically feasible with an electricity selling price or BPP of 55.26 cUSD/kWh (Rp9,117.90/kWh). However, when compared to the BPP of PLTD-based electricity on Seira Island of Rp 6,699/kWh, the BPP of the PLTS + BESS system is higher.



**Figure 2.** Comparison of BPP PLTD and PLTS on Seira Island  
Source: Author's analysis (2025)

Based on the above, the conversion of PLTD to solar power plants on Seira Island cannot be fully implemented (100% PLTD replacement) because it can cause an increase in BPP of electricity by Rp2,418.9/kWh. This condition is also the same as previous research on Enggano Island (Dyah Ayu Kartika Sari et al., 2022) which showed that in the early stages, the conversion of PLTD to PLTS+BESS in full caused the BPP of PLTS+BESS to be higher than the existing PLTD.

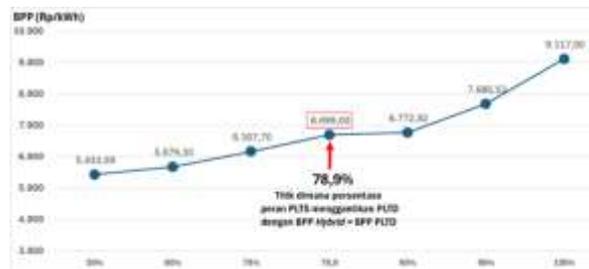
### **Optimal Capacity of PLTD to Solar Power Plant Conversion on Seira Island**

The optimization strategy for the conversion of PLTD to solar power plants on Seira Island is not only about changing energy sources, but also about how to ensure that electricity availability is maintained for 24 hours at an affordable cost. Determining the capacity of solar power plants and BESS to replace the role of PLTD is a very crucial aspect in this process. If the installed capacity is too small, then the electricity needs cannot be fully met so that the dependence on PLTD remains high. On the other hand, if the capacity is too large, the investment cost becomes expensive and will have an impact on the increase in the cost of supply (BPP) of electricity. Therefore, there needs to be a balance between generation capacity, energy storage capacity, and people's needs for reliable electricity. In a previous study conducted in Mentawai (Sari & Nazir, 2015), the larger the portion of solar PV, the greater the initial investment cost (initial capital), so an ideal proportion is needed between solar PV and PLTD to keep the hybrid system efficient.

Feasibility Analysis of Converting Diesel Power Plants (PLTD) to Solar Power Plants (PLTS) on Seira Island in Order to Reduce Electricity Supply Costs

In the context of Seira Island, if the PLTD conversion is carried out in full (100%), the calculation results show that the BPP PLTS + BESS is higher than the existing BPP PLTD. This condition indicates that the energy transition cannot be carried out with a large, one-step approach that is instantaneous. Gradual planning is needed taking into account all technical, financial, and environmental aspects. As per research on Kawaluso Island (Ilham Amba & Dalimi, 2023b), a hybrid scheme with a combination of solar power and PLTD is more efficient than full conversion of solar power because it is able to maintain a balance between cost and continuity of energy supply.

The analysis that will be carried out in determining the optimal solar PV capacity in order to maximize BPP savings, which refers to the Cost Optimization Theory where the optimal capacity is the capacity that minimizes the total cost of the system or reaches the break-even point between two alternative technologies ( $BPP_{Hybrid} = \text{initial } BPP_{PLTD}$ ). Based on the analysis carried out with the financial model of solar PV, the relationship between the percentage of conversion of PLTD to solar PV and BPP of electricity can be described as follows:



**Figure 3.** Simulation of PLTD to PLTS+BESS Conversion Optimization  
Source: Author's analysis (2025)

Based on the results of the analysis of the optimization of the role of solar power plants in the hybrid generation system of solar PV–PLTD, a clear relationship was obtained between the percentage contribution of solar power plants and the value of electricity BPP, whereby an increase in the share of energy produced by solar PV causes the BPP value of the hybrid system to gradually rise (Sari et al., 2022). At a solar PV penetration rate of 50%, the BPP value was recorded at IDR 5,433.09/kWh, increasing to IDR 5,679.30/kWh at 60% penetration and IDR 6,167.70/kWh at 70% penetration. This increase in BPP is mainly influenced by the higher investment requirements for solar PV and batteries needed to maintain system reliability.

The optimization results show that the economic optimum occurs at a solar PV penetration of 78.9%, where the BPP value of the hybrid system reaches IDR 6,699.00/kWh, which is equal to the existing BPP PLTD. This point represents a break-even condition, where increasing the share of renewable energy no longer results in higher electricity supply costs than a system fully based on diesel generation.

If the penetration of solar power plants is further increased beyond this point, the BPP value of the hybrid system becomes higher than the BPP of PLTD. This can be seen at 80% penetration, where the BPP reaches IDR 6,772.92/kWh, rising to IDR 7,686.53/kWh at 90%, and reaching IDR 9,117.90/kWh at 100% solar PV penetration. This condition indicates that

very high dominance of solar power plants requires larger battery capacity and additional supporting systems, which significantly increases the total system cost.

Thus, it can be concluded that a solar power plant penetration level of 78.9% is the best optimization result in this study, as it maximizes the use of renewable energy while keeping BPP competitive and comparable to conventional diesel plants. This point serves as the optimal technical–economic recommendation for the implementation of the PLTS–PLTD hybrid system. A similar pattern was also found in a previous study on the development of solar power plants on Kerasian Island (Syairozie et al., n.d.), where the highest efficiency was not achieved at 100% solar PV, but at a certain hybrid proportion, namely when the share of solar power plants reached 90.6%.

**Potential BPP Savings and Environmental Impact (Carbon Emissions)**

The implementation of the PLTD-PLTS hybrid generation system will have a direct influence on the electricity BPP produced. Quantitatively, the potential savings of BPP are analyzed based on the difference between the existing BPP PLTD and the BPP hybrid system at various levels of penetration of the PLTS (BPP PLTD - BPP hybrid). In the initial condition without solar PV penetration (0%), the entire generation load was met by PLTD with a BPP of Rp 6,699/kWh which was used as a comparison baseline.

The calculation results show that at 50% solar PV penetration, hybrid BPP has decreased to Rp 5,433.09/kWh, so that the difference in BPP is obtained of Rp 1,265.91/kWh or equivalent to Rp 8.7 billion per year (assuming kWh of 6.87 GWh/year). At 60% and 70% penetration, BPP savings still occur at IDR 1,019.70/kWh (IDR 7.01 billion/year) and IDR 531.30/kWh ((IDR 3.65 billion/year), respectively.

At the optimal penetration of 78.9%, where there is no savings in BPP of electricity because this point is a break-even point so that (BPP PLTD = BPP hybrid). At a higher penetration rate of solar PV, which is 80%, 90% and 100%, it no longer provides cost savings, but rather causes a significant increase in BPP or shows a negative trend. At 80% penetration, the BPP difference is only -IDR 73.92/kWh (-IDR 0.51 billion/year), 90% penetration is -IDR 987.53/kWh (-IDR 6.79 billion/year) and 100% penetration is -IDR 987.53/kWh (-IDR 6.79 billion/year). This condition indicates an increase in system costs due to the need for additional investment, system integration, and backup plant operation.

**Table 6.** The Impact of BPP on the Conversion of PLTD to PLTS+BESS

Uraian	Satuan	Penetrasi PLTS terhadap PLTD								
		0%	50%	60%	70%	78,90%	80%	90%	100%	
BPP Hybrid	(Rp/kWh)	6.699,00	5.433,09	5.679,30	6.167,70	6.699,00	6.772,92	7.686,53	9.117,90	
Dampak BPP	(Rp/kWh)	-	1.265,91	1.019,70	531,30	-	-	73,92	- 987,53	-2.418,90
	Rp. M	-	8,70	7,01	3,65	-	-	0,51	- 6,79	- 16,63

Source: Author's analysis (2025)

Thus, based on the results of the analysis of the difference between BPP PLTD and BPP hybrid, the penetration rate of solar PV in the range of 50%-70% is the most optimal condition to achieve cost efficiency in electricity supply.

In addition to the impact of BPP on electricity, the impact on the environment (carbon emissions) was also analyzed. The potential for environmental savings is based on the difference between existing PLTD emissions and hybrid system emissions at different levels Feasibility Analysis of Converting Diesel Power Plants (PLTD) to Solar Power Plants (PLTS) on Seira Island in Order to Reduce Electricity Supply Costs

of solar PV penetration (PLTD Emissions - Hybrid Emissions). In the initial condition without solar PV penetration (0%), the entire generation load is met by PLTD PLTD electrical energy production reaches 6,873,100 kWh per year, so the amount of emissions can be calculated by the formula:

$$\text{Emisi CO}_2 = E_{PLTD} \times SFC \times EF_{fuel}$$

with:

CO<sub>2</sub> emissions = Total carbon emissions (kg CO<sub>2</sub>)

E<sub>PLTD</sub> = PLTD-generated electrical energy (kWh),

SFC = Specific Fuel Consumption (liter/kWh),

EF = Emission Factor solar (kg CO<sub>2</sub>/liter).

The assumption of SFC for the Seira Island PLTD is 0.337 liters/kWh (source: PT PLN (Persero) which is still in the range of 0.25–0.35 liters/kWh (IEA, 2020). As for the diesel emission factor in Indonesia is in the range of 0.741 kg CO<sub>2</sub>/kWh emission factor (source: Ministry of Energy and Mineral Resources), the emission calculation for PLTD Seira Island is:

CO<sub>2</sub> emissions = E × SFC × E<sub>fuel</sub>

CO<sub>2</sub> emissions = 6,873,100 kWh x 0.337 liter/kWh x 0.741 kg CO<sub>2</sub>/kWh

CO<sub>2</sub> emissions = 1,716,330 kg CO<sub>2</sub>

The amount of emission value of 1,716 tons of CO<sub>2</sub> per year is a baseline that describes the current condition without converting PLTD to solar PV. As the penetration of solar power plants increased to 50%, PLTD emissions decreased to 858,165 kg CO<sub>2</sub>, showing a reduction in emissions by 50%. This downward trend continues at 60% to 90% penetration, where emissions are proportionately reduced following the decline in PLTD's electricity production due to the shift in energy supply to emission-free solar sources.

**Table 7.** Impact of Carbon Emissions on the Conversion of PLTD to PLTS+BESS

Uraian	Satuan	Penetrasi PLTS terhadap PLTD							
		0%	50%	60%	70%	78,90%	80%	90%	100%
Produksi PLTD	kWh	6.873.100	3.436.550	2.749.240	2.061.930	1.450.224	1.374.620	687.310	-
Emisi	kg CO <sub>2</sub>	1.716.330	858.165	686.532	514.899	362.146	343.266	171.633	-
Dampak Emisi	kg CO <sub>2</sub>	-	858.165	1.029.798	1.201.431	1.354.184	1.373.064	1.544.697	1.716.330

Source: Author's analysis (2025)

The value of the emission impact in the table above shows the accumulation of carbon emissions that have been successfully suppressed thanks to the use of solar PV. At 70% penetration, for example, avoidable emissions reach 1,201,431 kg of CO<sub>2</sub>, and increase to 1,544,697 kg of CO<sub>2</sub> at 90% penetration. Under ideal conditions of 100% solar PV penetration, all carbon emissions from PLTD can be eliminated, resulting in a potential emission reduction of 1,716,330 kg CO<sub>2</sub> per year. These results confirm that the integration of solar power plants not only plays a role in energy diversification, but also becomes an effective strategy in mitigating climate change and reducing environmental impacts.

## CONCLUSION

The planned use of solar power plants can be able to replace the role of PLTD in providing electrical energy on Seira Island in a sustainable manner with energy storage support (batteries) for round-the-clock electricity needs (24 hours). The economics of solar power for PLTD conversion are considered feasible to be implemented, but if the conversion is carried out fully (100%), the BPP of solar power is still higher than that of BPP PLTD (initial BPP). The most optimal configuration of solar power and BESS capacity to be implemented on Seira Island is 78.9% which is able to balance between the adequacy of energy supply, the reliability of the electrical system, and the cost efficiency of electricity supply. The conversion of PLTD to solar PV has a positive impact on reducing the cost of providing electricity and reducing environmental impact. Reducing the use of diesel fuel directly reduces greenhouse gas emissions and environmental pollution, thereby supporting clean energy transition efforts and achieving national emission reduction targets. Thus, the implementation of solar power plants on Seira Island is in line with the national energy policy and commitment to sustainable development

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