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Evaluation Study of Rooftop Solar Power System (RSPS) Utilisation Off Grid System at Ash Yard Office of Steam Power Plant (SPP) Mine Mouth (MT) Sumsel-82x660 MW

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Abstract - **Indonesia is currently facing various challenges in meeting its national energy needs. About 60% of the country's electricity production depends on coal, making it crucial to reduce this dependence to achieve energy balance, enhance energy resilience, and develop environmentally friendly renewable energy sources.**

In this study, the feasibility of investing in off grid solar rooftop systems is evaluated, considering technical performance, environmental impact, and economic aspects, including installation costs and potential energy savings.

This research proves that the design and installation of the off grid rooftop solar power system function well, with a performance ratio (PR) value of 83.22%, indicating that the system meets the expected standards (above 70%). In addition, the off grid rooftop solar power system is capable of producing electricity with an average annual value of 5,572 kWh. This off grid rooftop solar power system contributes to the reduction of carbon emissions at the research site by 50,531 tons of CO_2e in one year, in line with the research objectives related to environmental aspects. The off grid rooftop solar power system at the Ash Yard Office is a feasible and profitable investment due to the power cable connection from the Sumsel-8 coal-fired power plant and the use of 20kV medium voltage electricity from PLN. It has a Payback Period of 19 (nineteen) years, which indicates that the investment in the rooftop solar power system at the Ash Yard Office is still worth pursuing because the Payback Period is shorter than the project's lifespan.

Keywords: Energy, Renewable, Sustainability, Investment.

I. INTRODUCTION

Energy is essential for fostering sustainable development in Indonesia, impacting social, economic, and environmental well-being. Effective and efficient energy management can yield numerous advantages in everyday life and contribute to mitigating environmental issues in the future. Conversely, the misappropriation of energy can result in numerous issues pertaining to the energy source itself.

Indonesia is presently confronting multiple hurdles in fulfilling its national energy requirements. A significant contributing element is the substantial reliance on fossil fuels, including petroleum, natural gas, and coal. Most power plants in Indonesia continue to depend on fossil fuel sources, particularly coal, which accounts for 60 percent of the nation's total electricity generation. As a leading coal-producing nation, diminishing reliance on coal presents a considerable problem [1].

PLTU or Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8is part of the government's 35 GW power plant development program, developed by the Independent Power Producer (IPP) PT Bukit Asam and China Huadian Hongkong Company Limited. As a result, this project is classified as a National Strategic Project (PSN), with construction starting in 2018 and initially planned to commence commercial operations in March 2021. However, due to the impact of COVID-19 and the readiness of the 500kV transmission, the project was completed and commenced commercial operations in October 2023. SPP Mulut Tambang (MT) Sumsel-8with a capacity of 2x660 MW has a 25-year power purchase agreement with PLN through the Build, Operate, Own, Transfer (BOOT) scheme.

SPP Mulut Tambang (MT) Sumsel-8 operates with a consumption of around 5,000,000 MT of coal each year, using supercritical technology known as clean coal technology. One opportunity to implement this supercritical technology is by improving the efficiency of the power plant, which can be achieved through reducing the air ratio, adjusting the flue gas temperature, increasing the steam pressure or temperature, adding reheating, and lowering the condenser pressure.

Indonesia is presently encountering multiple hurdles in fulfilling its national energy requirements. A significant contributing element is the substantial reliance on fossil fuels, including petroleum, natural gas, and coal. Most power plants in Indonesia continue to depend on fossil energy sources,

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particularly coal, which accounts for 60 percent of the nation's total electricity generation. As a leading coal-producing nation globally, diminishing reliance on coal presents a considerable problem.

SPP Mulut Tambang (MT) Sumsel-8can produces approximately 400,000 tons of FABA per year. This considerable amount requires a large area of land to accommodate the FABA for 25 years. In the coal sale and purchase agreement, PT Bukit Asam Tbk, as the coal supplier for the SPP Mulut Tambang (MT) Sumsel-8, has the obligation to provide a storage area for the ash resulting from the coal combustion. Considering that the SPP Mulut Tambang (MT) Sumsel-8 is surrounded by Mining Business Licenses (IUP) with abundant coal content, the FABA storage location (ashyard) was chosen to be far from SPP Mulut Tambang (MT) Sumsel-8, approximately 8 km within the palm oil plantation area and away from residential areas.

To meet the electricity needs in the Ash Yard area, SPP Mulut Tambang (MT) Sumsel-8 chose to utilize solar energy as an alternative energy source to be converted into electricity through the installation of an off gridRooftop Solar Power System (RSPS). This aims to facilitate meeting electricity needs, support the government's program in the energy transition towards green energy, which aims to reduce fossil energy consumption for its own needs.

On the other hand, before deciding to proceed with or recommend the widespread use of off grid solar power systems, it is important to conduct a comprehensive evaluation study from various aspects, including technical, environmental, and economic aspects. This study will provide an overview of whether the significant investment in the installation of off grid rooftop solar power systems is commensurate with the benefits obtained, both in terms of long-term energy savings, emission reduction, and the potential return on investment that can be achieved.

In the results of another study [2], the research results indicate that the investment in an off grid rooftop solar power system in a boarding house in Surabaya City, using the DPP, NPV, IRR, and PI calculation methods, is considered feasible to implement. The conclusion shows that the installation of this solar rooftop system is a good alternative to increase energy efficiency and reduce operational costs in the boarding house in Surabaya City.

In the results of another study [3], The results of this study show various aspects of photovoltaic (PV) system performance, including factors that affect electricity production such as sunlight intensity, temperature, and conversion efficiency. In addition, this research also discusses the factors that can be optimized as well as the potential to improve the performance of the PV system. The conclusion of this research provides detailed information regarding the components and specifications of the flood early warning system at the Karebbe Hydroelectric Power Plant, specifically those installed at the Km 50 Remote Warning Station. This research also identifies factors that affect the performance of the solar PV system, particularly the impact of weather or the rainy season on autonomy days and the size of the battery and PV array, which can serve as a reference for improving the Karebbe FEWS system.

In the results of another study [4], conducting an analysis of the planning of a Hybrid Solar Power Plant system from an economic perspective using HOMER software. The methods applied to evaluate investment costs and cash flows during the investment period include Net Present Value (NPV), Benefit–Cost Ratio (B-CR), and Discounted Payback Period (DPP).

In the results of another study [5], Conducting a comparative analysis by utilizing the design of two brands of solar panels with a capacity of 720Wp and two brands of batteries with a capacity of 160Ah through PVSyst 7.0 software. The simulation results show that the highest amount of supplied energy occurs in the third variation, which is 674.51 kWh per year. In addition, an economic evaluation was conducted to compare the economic aspects of solar power plants (PLTS) with other alternative power sources, such as generator sets and the use of batteries charged by PLN.

In the results of another study [6], Research on the performance analysis of the grid-connected photovoltaic (PV) system at the Institute University of Technology (IUT) in Mulhouse, France, with a capacity of 2.4 kWp, was conducted based on data monitored from August 2018 to May 2020. The recorded energy generated during that period showed figures of 968.43 kWh, 3,246.47 kWh, and 1,382.75 kWh for the years 2018, 2019, and 2020. The total energy generated and the CO_2 emissions produced during the system's lifespan were recorded at 5,597.65 kWh and 4.17 tons, respectively.

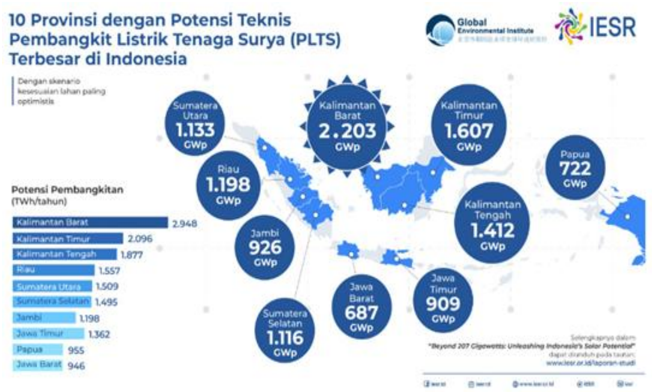

Figure 1: Provinces with the Largest Technical Potential for Solar Power System in Indonesia

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Indonesia is one of the countries in the world with a very large potential for solar energy sources. According to data from the Rencana Umum Energi Nasional (RUEN), the potential for solar energy generation in Indonesia is estimated to reach 207.89 GW with an intensity of 4.80 kWH/m^2/day.

Based on this, the Indonesian government has set a target for solar energy utilization, which is expected to reach 6.5 GW by the end of 2025 and 45 GW by the end of 2050, equivalent to 22% of the total solar potential available in Indonesia. The potential for solar energy in Indonesia is evenly distributed across almost all provinces. According to data from the Global Environmental Institute (2022), the province with the largest solar energy potential is West Kalimantan, with a generation capacity of 2,948 TWh per year, followed by East Kalimantan with 2,096 TWh per year, Central Kalimantan with 1,877 TWh per year, Riau with 1,557 TWh per year, and South Sumatra with 1,495 TWh per year.

The potential for solar energy in Indonesia is very significant, reaching around 7,714.6 GW (Gigawatts). South Sumatra Province has a solar energy potential of around 17,233 Megawatt-peak (MWp). However, most of this potential has not yet been utilized, due to Several challenges still persist, such as land limitations and relatively unprofitable investments. However, solar power plants (PLTS) are expected to grow at least from rooftops for independent electricity needs. Based on data from the South Sumatra Energy and Mineral Resources Office (ESDM), the installed capacity of solar energy in South Sumatra currently stands at 7.75 megawatt-peak (MWp). That number is still far below the solar energy potential in South Sumatra, which is 17,233 MWp.

Solar Power Plants (PLTS) are generating systems that utilize solar energy as the main source through the use of solar cells (photovoltaic) to convert solar radiation into electrical energy. Solar cells consist of thin layers made from pure silicon (Si) semiconductor materials as well as other semiconductor materials [7].Solar Power Plants (PLTS) generates direct current (DC) electricity from sunlight, which can be converted into alternating current (AC) electricity if needed.Solar Power Plants (PLTS) are a clean and environmentally friendly energy source, with no rotating components, no noisy sounds, and no waste that can harm the surrounding environment.

The main obstacles in the solar power plant (PLTS) market are the high investment costs per Watt of power generated, as well as the dependence on imports of several raw materials for PLTS components, especially solar cells [8].Therefore, the development of the local solar cell industry is very important for the advancement of solar power plants in the future. In addition, attractive electricity purchase tariff policies for investors are also a crucial factor in driving the growth of private investment in solar power plant development [9].

In this research aims to evaluate the investment feasibility in the installation of off grid solar power systems after they have been installed for 1 (one) year, considering technical factors related to system performance, environmental impacts that may arise from the use of renewable energy, as well as economic aspects including installation costs, maintenance, potential energy savings, and potential return on investment. With this study, it is expected to provide clearer recommendations for the community and stakeholders regarding the use of off grid solar power plants in the Sumsel-8 coal-fired power plant area, as well as the exploration of backup options to enhance system reliability.

Based on the application and configuration, PV systems can be divided into three types: off grid PV plants, on-grid PV plants, and combinations with other power generation systems known as hybrid PV systems.

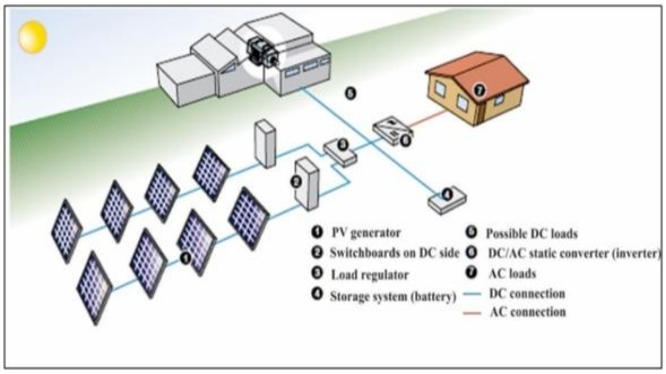

Figure 2: The working principle of off-grid solar power plants (ABB, 2014)

II. RESEARCH METHOD

This research falls into the evaluative category using descriptive and exploratory methods to collect comprehensive data and information. The research process includes planning identification, assessment of the realized amount of electricity generated, evaluation of technical aspects based on the performance of the rooftop solar power system, analysis of environmental aspects related to greenhouse gas emission reduction, and evaluation of economic aspects focusing on investment feasibility.

III. RESULTS AND DISCUSSIONS

The planning data for rooftop solar power systems (PLTS) was obtained through the identification and data collection from the planning documents for the utilization of

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off grid rooftop solar power systems at the Ash Yard Office of PLTU Sumsel-8, as one of the pieces of information that will support the evaluation results of the utilization of off grid rooftop solar power systems at the Ash Yard Office of PLTU Sumsel-8.

The roof area where the solar power system (PLTS) has been installed, based on the DED (detail engineering design) measurements, is 330.00 m² with dimensions of 3000 mm X 1100 mm. The roof area utilized for the installation of the rooftop solar power system is 67%, with a total of 102 solar panels, each measuring 2166 x 1002 mm, of the monocrystalline type with a capacity of 440 Wp, brand Jinko Solar, with an inclination angle of 10° and an azimuth angle of 89°. The inverter used is a Tgood brand, model CSCU1, with one unit having an efficiency of 98.9%. The total output capacity of the rooftop solar power plant is 44.88 KWp and it uses a 300 KWh lithium battery connected in parallel to the DC side of the converter. Here are the installed solar panels and the assembly diagram of the solar panels.

Figure 3: Solar Panel Installed

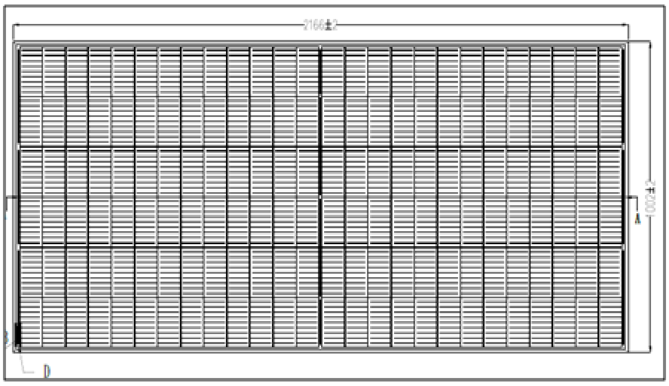

Figure 4: Assembly Diagram Panel

The intensity of solar radiation at the ash yard building of PLTU Sumsel-8 was measured based on NASA calculations (2023), where the average solar radiation intensity is 4.905 kWh/m^2/day.

Table 1: Solar Radiation Intensity at the Ash Yard Building of PLTU Sumsel-8

2020		2021		2022	
BULAN	INTENSITAS RADIASI MATAHARI (kWh/m2/hari)	BULAN	INTENSITAS RADIASI MATAHARI (kWh/m2/hari)	BULAN	INTENSITAS RADIASI MATAHARI (kWh/m2/hari)
Januari	4,56	Januari	4,43	Januari	4,38
Februari	4,56	Februari	4,9	Februari	4,72
Maret	5,15	Maret	5,24	Maret	5,16
April	5,22	April	5,13	April	5,15
Mei	4,88	Mei	4,86	Mei	4,73
Juni	4,52	Juni	4,85	Juni	4,77
Juli	4,85	Juli	4,74	Juli	4,71
Agustus	5,33	Agustus	4,97	Agustus	5,13
September	5,23	September	5,05	September	5,04
Oktober	5,11	Oktober	5,17	Oktober	5,12
November	5,13	November	5,24	November	5,18
Desember	4,61	Desember	4,79	Desember	4,77
RATA-RATA					4,905

Sumber: (NASA 2023)

The investment cost for the rooftop solar power plant at the Sumsel-8 coal-fired power plant office includes expenses such as solar panel module costs, inverter costs, material costs, installation costs, operation and maintenance training costs, and the operation feasibility certificate (SLO). The total initial investment cost incurred for the installation of rooftop solar power plants with a total capacity of 44.88 kWp is Rp1,110,890,009 (One billion one hundred ten million eight hundred ninety thousand nine rupiah).

Table 2: Investment in Rooftop Solar Power Plant Development Off-grid system for the Ash Yard Office of Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8

NO	DESKRIPSI	VOLUME	SATUAN	HARGA SATUAN	BIAYA
I. Solar Module System					
1	Solar PV Module	102	pcs	2.650.000	270.300.000
2	Solar Mounting System	59.670	wp	422	25.180.740
II. Optical Storage Integrated System					
1	Off grid Inverter	1	set	471.250.000	471.250.000
2	BEMS + Rack + BMS	300.000	Wh		
III. Material					
1	Installation Material	59.670	wp	977	58.297.590
2	PV Cables	59.670	wp	149	8.890.830
3	AC Cables	59.670	wp	204	12.172.680
IV. Project Work					
1	Services	13,5%	lot	846.091.840	114.222.398
2	SLO	59.670	lot	300	17.901.000
3	O&M Training	59.670	lot	531	31.684.770
Subtotal					1.009.900.008
Pajak PPN 10%					100.990.001
TOTAL					**1.110.890.009**

The calculation of the actual amount of electrical energy produced by the off grid rooftop solar power system at the Ash Yard PLTU Sumsel-8 office is carried out through recording in the inverter monitoring system. The recording is carried out over a period of 1 (one) year after the installation of the rooftop solar power system. The data will be used as one of the parameters in analyzing the contribution of the generated electrical energy, the performance analysis of the rooftop solar power system, the analysis of greenhouse gas emission

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reduction, and the investment feasibility analysis resulting from the utilization of the off grid rooftop solar power system as an effort to transition energy from fossil fuel power plants.

In the data from the calculation of the realized amount of electricity generated by the rooftop solar power plant at the Ash Yard office of PLTU Sumsel-8 over a period of 1 (one) year after installation, it can be seen in the table below:

Table 3: Electricity Production from Offgrid Rooftop Solar Power Plant at Ash Yard Office of Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8

NO	YEAR	MONTH	ELECTRICITY PRODUCTION (kWh)
1	2022	January	4.197
2		February	5.465
3		March	6.547
4		April	6.334
5		May	6.368
6		June	5.322
7		July	5.542
8		August	6.207
9		September	5.686
10		October	4.994
11		November	5.074
12		December	5.122
TOTAL			**66.859**
MONTHLY AVERAGE			**5.572**
DAILY AVERAGE			**183**

Based on the results of data identification for the planning of the construction of an off grid rooftop solar power plant at the Ash Yard Office of PLTU Sumsel-8 using the documentation study method as described above, it can be interpreted as follows:

a. Based on table 3, the Ash Yard Office of Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8, which is used as a case study in this research, has a solar radiation intensity of 4.905 kWh/m^2/day, with peak values occurring in August-November 2022 and the lowest values occurring in January 2022. As is known, Indonesia experiences rainy and dry seasons. During the rainy season, the position of the clouds tends to block the intensity of sunlight reaching the Earth's surface. Thus, in the months of December-February, the intensity of sunlight is the lowest throughout the year. On the other hand, Indonesia experiences the dry season, with clear skies that do not obstruct the sunlight reaching the Earth's surface, and from August to November 2022 is the peak period of high sunlight intensity reaching the Earth.

b. The roof area utilized for the installation of solar panels at the Ash Yard Office of Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8, based on measurements and DED evaluation, is 67%, which complies with the RUEN mandate (minimum 30%).

c. Based on table 2, the investment cost for the rooftop solar power plant at the Ash Yard Office of Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8 is Rp.1,110,890,009 (One billion one hundred ten million eight hundred ninety thousand nine rupiah); with a total capacity of 44.88 kWp, this value is more economical compared to the other two methods, namely the power cable installation from Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8 amounting to Rp.7,486,040,000 and the use of 20kV medium voltage electricity from PLN amounting to Rp.14,074,825,000 as attached in Appendix 2.

d. Based on the calculation results of the realized electrical energy output, the off grid rooftop solar power system installed at the Ash Yard Office of Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8shows an increasing trend during the research period. This indicates that the installed rooftop solar power system is capable of providing a significant contribution to electricity, thereby saving electricity costs amounting to Rp. 87,797,902 per year and reducing greenhouse gas emissions by 50.531 tons of CO_2e per year.

e. Based on table 3, the off grid rooftop solar power system installed at the Ash Yard Office of Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8is capable of producing an average of 5,572 kWh of electrical energy per year. The amount of energy produced by the solar power plant is capable of contributing approximately 13-14% to the target development of solar power plants in South Sumatra province, in accordance with the mandate of the National Energy Policy (RUEN) of 2017, which is 42.4 MW per year in 2022 and 296.6 MW per year in 2025.

The evaluation of technical aspects is conducted through the performance of the rooftop solar power system by calculating three (3) system performance parameters related to energy production, solar resources, and overall system loss effects, namely: final yield (YF), reference yield (YR), and performance ratio (PR) based on the IEC 61724 standard [11].The calculation of the performance ratio (PR) value under the existing conditions of the rooftop solar power system is important to determine how the performance of the rooftop solar power system is after 1 (one) year of installation. Here are the variables used in the evaluation of the technical aspects in this study.

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Table 4: Variable Technical Aspects

Variable	Unit	Value
Input		
Production of electricity from rooftop solar power system	kWh	66.859
Total output capacity of rooftop solar power system	kWp	44,88
Intensity of solar radiation	$kWh/m^2/hari$	1.790
Reference radiation under ideal conditions/STC (1.000 W/m^2)	W/m^2	1
Output Antara		
Final Yield (YF)	Hour	1.490
Reference Yield (YR)	Hour	1.790
Final Output		
Performance Ratio (PR)	%	83,24

The final yield (YF) can be obtained from the calculation of electricity production over a period of 1 (one) year after the installation of the rooftop solar power system (kWh) as listed in Table 3, divided by the peak power generated from the PV array (kWp). The final yield (YF) value of the rooftop solar power plant at the Ash Yard of Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8can be calculated using the following formula:

$$YF = Epv/Po$$
$$YF = 66859/44{,}88$$
$$YF = 1490\ h$$

The reference yield (YR) is the total value of solar radiation on a surface area of the Earth (Ht) measured in kWh/m², calculated based on NASA data (2022) as listed in Table 3, divided by the reference radiation under ideal/STC conditions (Gstc) with a value of 1,000 W/m². The reference yield (YR) value of the rooftop solar power plant at the ash yard of Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8can be calculated using the following formula:"The final yield (YF) can be obtained from the calculation of electricity production over a period of 1 (one) year after the installation of the rooftop solar power system (kWh) as listed in Table 2 divided by the peak power generated from the PV array (kWp)." The final yield (YF) value of the rooftop solar power plant at the Ash Yard office of Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8can be calculated using the following formula:

$$YR = Ht/Gstc$$
$$YR = (1790\ kWh/m^2)/(1\ kW/m^2)$$
$$YR = 1790\ h$$

The quality of a solar power plant (PLTS) can be assessed through the performance ratio (PR) value. Performance ratio (PR) expressed in percentage form, where performance ratio is defined as the comparison between the power generated by the DC current and the output power of the AC current. The performance ratio (PR) value of the rooftop solar power plant at the Ash Yard of PLTU Sumsel-8 can be calculated using the following formula:"The reference yield (YR) is the total value of solar radiation on a surface area of the Earth (Ht) measured in kWh/m², calculated based on NASA data (2022) as listed in Table 4.3, divided by the reference radiation under ideal/STC conditions (Gstc) with a value of 1,000 W/m²." The reference yield (YR) value of the rooftop solar power plant at the Sumsel-8 coal-fired power plant can be calculated using the following formula:"The final yield (YF) can be obtained from the calculation of electricity production over a period of 1 (one) year after the installation of the rooftop solar power system (kWh) as listed in Table 2 divided by the peak power generated from the PV array (kWp)." The final yield (YF) value of the rooftop solar power plant at the Ash Yard office of Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8can be calculated using the following formula:

$$PR = YF/YR \times 100\%$$
$$PR = (1490\ h)/(1790\ h) \times 100\%$$
$$PR = 0{,}8324 \times 100\%$$
$$PR = 83{,}24\%$$

Based on Table 3 and the calculations above, the efficiency analysis results show that the off grid rooftop solar power system at the Ash Yard office of PLTU Sumsel-8 has good performance after one year of installation, with an average performance ratio (PR) value of 83.22%.This also shows that 16.78% of the solar energy potential during that period was not converted into electrical energy, which could be due to several factors such as energy losses and inefficiencies in the distribution components and system.

The factors that play an important role in ensuring the off grid rooftop solar power system at the Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8office operates optimally and provides maximum benefits are: first, the optimal system design, which relates to capacity planning according to energy needs and determining the correct orientation and tilt angle of the solar panels to maximize sunlight absorption; second, the quality of the rooftop solar power components, such as a good inverter that supports the efficient conversion of DC to AC and is resistant to extreme weather conditions; third, a supportive location and environmental conditions, free from shading and with optimal solar radiation levels. Fourth, regular and optimal operation and maintenance.

The evaluation of environmental aspects is conducted by using the baseline emission reduction calculation approach

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and the electricity production approach. Here are the variables used in the evaluation of environmental aspects in this research:

Table 5: Variable Environmental Aspect

Variable	Unit	Value
Input		
Baseline emissions for period y	MWh	40,174
Baseline emission factor	CO_2/MWh	0,8
Intensity of solar radiation	kWh/m^2/day	4,905
Average technical transmission and distribution losses		0,2
Installed capacity of each type of power plant	kWp	44,88
Degradation of manufacturing efficiency for crystalline cells by		0,5
Solar radiation per region according to the latest publication	kWh/m^2/day	4,905
Output Antara		
Emisi Baseline (EB(y))		50,531
Emisi Aksi Mitigasi (EP(y))		0
Final Output		
Reduction of emissions by mitigation actions in period y (PE(y))		50,531

Mitigation actions in emission reduction are important steps aimed at reducing GHG emissions from fossil fuel combustion by utilizing solar power plants (PLTS). Baseline Emissions are the amount of energy produced that would be equivalent if no mitigation actions were taken. Baseline Emissions are usually used as a reference point to measure the success of mitigation activities or low-emission development. Baseline emissions in this study are measured based on the installed capacity data of renewable energy power plants as follows:

$$EBL,y = KT \times (1-DEy) \times Ry \times 365$$
$$= 44{,}88 \text{ kWp} \times (1-0{,}5) \times 4{,}905 \text{ kWh/m}^2\text{/hari} \times 365$$
$$= 40{,}174 \text{ MWh}$$

$$Eby = EBL,y \times FEy \times 1/((1-TDL))$$
$$= 40{,}174 \text{ MWh} \times 0{,}8 \text{ tCO}_2 \times 1/((1-0{,}2))$$
$$= 50{,}531 \text{ ton Co}_2$$

Thus, the reduction in emissions by mitigation actions in period y (PE(y)) can be calculated as follows:

$$Pey = EBy - EPy$$
$$= 50{,}531 - 0$$
$$= 50{,}531 \text{ ton CO}_2$$

Based on the calculation results, the reduction in greenhouse gas emissions through the utilization of rooftop solar panels at the Ash Yard office amounts to 50.531 tons of CO_2 in one (1) year. That amount contributes significantly, where every 1% increase in electricity production will result in a 1.05% reduction in CO_2 emissions. The results of this calculation can serve as an initial step to start the development of utilizing rooftop solar power plants at other offices of Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8, as mandated in the RUEN, which requires the use of solar energy to be at least 30% of the total roof area of the building. If the policies implemented by the leaders within the Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8 environment in developing solar energy can be realized, including the plan to build rooftop solar power plants at several points in Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8, then there will be a significant reduction in greenhouse gas emissions contributed through the utilization of off grid rooftop solar power systems in the Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8 environment, while also increasing the share of renewable energy in the energy mix in South Sumatra Province and the transition from fossil energy to green energy (renewable energy).

The evaluation of the economic aspect is conducted through investment feasibility analysis by calculating the Net Present Value (NPV), Benefit Cost Ratio (BCR), and Payback Period (PP) of the rooftop solar power utilization project based on initial investment costs, operational and maintenance costs, as well as the benefits obtained within a period of one year after the installation of the rooftop solar power system, grounded in existing theories and literature.

Table 6: Investment feasibility variables for the utilization of rooftop solar power plants at the Ash Yard office of Steam Power Plant (SPP) Mulut Tambang (MT) Sumsel-8

Variable	Unit	Value
Input		
Initial investment in rooftop solar power plants	Rp	1.110.890.009
Operational and maintenance	Rp	8.460.918
Basic electricity tariff	Rp	1.699
The amount of electricity generated by rooftop solar power plants	kWh	66.859
Discount factor	%	3,5%
Inflation rate	%	2,56%
The rate of decline in photovoltaic performance	%	0,005
Output Antara		
Present Worth Cost	Rp	2.094.462.934
Present Worth Benefit	Rp	2.121.101.775
Net Cash Flow	Rp	1.137.528.850
Final Output		

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Net Present Value	26.638.841
Benefit Cost Ratio	1,01
Payback Period	13,03

The feasibility evaluation of the off grid rooftop solar power plant investment at the Ash Yard office of PLTU Sumsel-8 is calculated using the electricity generation data over a period of 1 (one) year, which amounts to 66,859 kWh. The initial investment cost of the rooftop solar power plant as listed in Table 1is Rp1,110,890,009, and the annual maintenance and operational cost is assumed to be 1% of the total expenditure on goods in the initial investment, which amounts to Rp8,460,918.00. For the purpose of technical economic analysis, the inflation rate is needed to determine the value of cash inflows and outflows in the current year. The inflation rate is 2.56% [12]. Discount rate data is also needed to determine the Present Value Factor (PVF) to calculate the future value of currency to its present value (Present Worth Benefit and Present Worth Cost), which is 3.5% [13].The complete cash flow from the rooftop solar power plant at the ash yard of PLTU Sumsel-8, considering the photovoltaic performance degradation rate of 0.005 [14].

NPV is the present value of future cash inflows, so with this method, the feasibility of the investment and future cash flow projections must be expressed in present value or discounted at an appropriate interest rate. NPV can be obtained from the Present Worth Benefit (PWB) minus the Present Worth Cost (PWC). Based on table 4.5, the total PWB is Rp2,121,101,775.00 while the PWC is Rp2,094,462,934.00, thus the NPV value is as follows:

$$
\begin{aligned}
\mathrm{NPV} &= \mathrm{PWB} - \mathrm{PWC} \\
&= \sum_{t=0}^{n} \mathrm{Cb_t}\,(\mathrm{FBP})_t - \sum_{t=0}^{n} \mathrm{Cc_t}\,(\mathrm{FBP})_t \\
&= \mathrm{Rp}2.121.101.775{,}00 - \mathrm{Rp}2.094.462.934{,}00 \\
&= \mathrm{Rp}26.638.841{,}00
\end{aligned}
$$

Based on the calculation results, an NPV value was obtained, indicating that the investment in the rooftop solar power plant at the Sumsel-8 coal-fired power plant office is feasible because it has an NPV value greater than zero (>0).

Benefit Cost Ratio (BCR) is calculated by emphasizing the comparative value between the revenue aspect (benefit) that will be obtained and the cost (cost) and investment (investment) aspects that will be borne by the existence of the project. BCR can be determined from the Present Worth Benefit (PWB) divided by the Present Worth Cost (PWC). Based on Table 5, the total PWB is Rp2,121,101,775.00 while the PWC is Rp2,094,462,934.00, thus the BCR value is as follows:

$$
\begin{aligned}
\mathrm{BCR} &= \frac{\mathrm{PWB}}{\mathrm{PWC}} \\
&= \frac{\sum_{t=0}^{n} \mathrm{Cb_t}\,(\mathrm{FBP})_t}{\sum_{t=0}^{n} \mathrm{Cc_t}\,(\mathrm{FBP})_t} \\
&= \frac{\mathrm{Rp}2.121.101.775{,}00}{\mathrm{Rp}2.094.462.934{,}00} \\
&= 1{,}01
\end{aligned}
$$

Based on the calculation results, a BCR value of 1.01 was obtained, indicating that the investment in the rooftop solar power plant at the Sumsel-8 coal-fired power plant is feasible because it has a BCR value greater than 1 (one), meaning the revenue generated over the project's economic lifespan exceeds the costs and investment.

Payback Period (PP) is used to determine the time required to recover the value of an investment. The method for calculating the Payback Period (PP) is by determining the time required (in years) for the estimated cumulative net cash flow to equal the initial investment. From table 4.6, it is known that the PP period lies between the 18th and 19th years, and more precisely, it can be calculated using the following formula:

$$
\begin{aligned}
\mathrm{PP} &= (n-1) + \frac{\text{Arus Kas Bersih Kumulatif tahun n}-1}{\text{Arus Kas Bersih tahun n}} \text{ x 1 tahun} \\
&= (19-1) + \frac{\mathrm{Rp}37425086}{\mathrm{Rp}78059106} \text{ x 1 tahun} \\
&= 18 + 0{,}47 \text{ x 1 tahun} \\
&= 19{,}47 \text{ tahun}
\end{aligned}
$$

Based on the calculation results, the PP value is 19.47 years, so it can be said that the investment in the rooftop solar plant at Ash Yard office is still worth continuing because the PP period is shorter than the project's lifespan.

IV. CONCLUSION

Based on the evaluation results, the technical aspects indicate that the design and installation of the off grid rooftop solar power system are functioning well, with a performance ratio (PR) of 83.22%, which shows that the system meets the expected standards (above 70%). In addition, the off grid rooftop solar power system is capable of producing electricity with an average annual value of 5,572 kWh. The amount of energy produced by the solar power plant can contribute approximately 13-14% to the solar power development target in South Sumatra province, in accordance with the mandate of the 2017 RUEN, which is 42.4 MW per year by 2022 and 296.6 MW per year by 2025. This shows that the utilization of this off grid rooftop solar power system can support the energy transition from fossil fuels to renewable energy at the Ash Yard PLTU Sumsel-8 within a one-year period. Based on the evaluation results, the environmental aspect at the research

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location shows that this off grid rooftop solar power system contributes to a reduction in carbon emissions at the research site by 50,531 tons CO_2e in one year, which aligns with the research objectives related to environmental aspects. Based on the evaluation results, the construction of an off grid rooftop solar power plant at the Ash Yard office is a feasible and profitable investment compared to the other two methods, namely power cable installation from PLTU Sumsel-8 and the use of 20kV medium voltage electricity from PLN, with a payback period of 19 (nineteen) years. Therefore, it can be said that the investment in the rooftop solar power plant at the Ash Yard office is still worth continuing because the payback period is shorter than the project's lifespan. Based on the evaluation results conducted in this study, the development of utilizing the off grid rooftop solar power system at the Ash Yard office can be continued because it provides good benefit impacts with several improvements, especially in environmental aspects as an effort to transition from fossil energy to renewable energy.

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