Economic Analysis of Hybrid Power Plant (Solar-Diesel) on Kawaluso Island, North Sulawesi

Muhammad Ilham Amba 1, Rinaldy Dalimi 1
1 Electrical Engineering Department, Faculty of Engineering, University of Indonesia, Depok, Indonesia
Email: muhammad.ilham014@ui.ac.id, rinaldydalimi@ui.ac.id

Abstract—Kawaluso Island is one of the outermost islands in Indonesia with a distance of 68 KM from the city of Tahunah or 5-10 hours by boat from the capital of the Sangihe Islands Regency, Tahunah. Currently, electricity on Kawaluso Island is supplied by a diesel power plant (PLTD) with a capacity of 200 kW. This condition causes Kawaluso Island to be electrified 12 hours per day. So that additional sources of power plant are needed so that the electricity on Kawaluso Island is on 24 hours a day. Therefore, a solar power plant (PLTS) is one of alternative as additional power for Kawaluso Island and reduces the cost of production. A diesel power plant where the price of industrial fuel reaches up to Rp. 24,500 and it make Cost of Energy Rp. 10,360/kWh. The method used in this study uses the Levelized Cost of Energy (LcoE) method. The results of the analysis show that the hybrid between diesel power plant and solar power plant 64 kWp and 72 kWp has a Life Cycle Cost (LCC) value of Rp24,389,601,114,40 and Rp. 20,589,498,278,40 With a Cost of Energy (COE) of Rp. 7,432 and Rp. 5,601/kWh. Net Present Value (NPV) obtained is positive. And the payback period is 3 and 9 years of investment and is categorized as feasible to continue.


Kata Kunci— Biaya Energi, Biaya Siklus Hidup, Energi Surya, Pembangkit Listrik Tenaga Hibrida, Pulau Kawaluso.

I. INTRODUCTION

Indonesia has a many islands with challenges of electricity. As we know all the big system electricity in big islands of Indonesia like a java bali or sumatera its already providen. But in the other cases like in the small island, they just reliable with diesel energy. Although currently renewable energy in Indonesia is starting growing up. Reliable with diesel energy can up the cost of generation and it doesn’t provitable or it will make a pollution in the environment. Kawaluso island is one of the outermost islands in northern Sulawesi Electricity in Kawaluso island depends from Diesel energy and it has 12 hour operation. With a distance of 68 KM from the city of Tahunah With the cost of generation up to Rp.10,360/kWh, its important to find the alternative energy to make lower cost of generation than diesel generator. Currently, the electricity condition on Kawaluso Island consists of a 160 meter Medium Voltage Network, a 1,368 meter Low Voltage Network and one sub station. Currently, Kawaluso Island has a diesel power plant with a capacity of 2 of 100 kW and operates 12 hours per day. Based on the operating data of the diesel power plant, the daily electricity consumption on the island of Kawaluso around 170 kWh to 200 kW. The current engines are used for daily electricity is Deutz F6L-912 engine and the Deutz F10L-413F engine in standby condition. Specific fuel consumption (SFC) condition of the F6L engine is 0.42 and the F10L engine is 0.91.

II. LITERATURE REVIEW

A. Hybrid Power Plant

Hybrid Power Plant is a power plant consisting of 2 or more generators with different energy sources. For example, such as a Solar Power Plant combined with a Diesel Power Plant. One of its functions is either if the sky is overcast and the sun disappears during the day, the power plant will be supplied by a diesel generator otherwise when diesel is off then the power plant will be driven by solar panels [1] or the cost of generation in a area can be reduced if one of the diesel power plant has higher cost of energy. Indonesia is located on the equator, so Indonesia has abundant sources of solar energy with
an average solar radiation intensity of around 4.8 kWh/m2 per day throughout Indonesia [2]. In planning a solar power plant, there are several components that must be prepared in the project. The main components included solar modules, batteries, and inverters.

a) Solar Modules

Solar panel is a device that converts sunlight energy into electrical energy by means of a photo voltaic effect, therefore it is also called a photovoltaic cell (Photovoltaic cell – abbreviated as PV). Solar panels consist of many solar cells or solar cells. Solar Cell is an active element that converts sunlight into electrical energy. Solar cells generally have a minimum thickness of 0.3 mm, which is made of slices of semiconductor material with positive and negative poles. The basic principle of making solar cells is to utilize the photovoltaic effect, which is an effect that can directly convert sunlight into electrical energy [3].

b) Battery

Battery is a tool that is used to store electrical energy so that we can use it at any time. Battery (battery) is an energy storage device that is charged by the flow of Direct Current (DC) from solar panels. Besides storing DC energy, the battery also functions to convert chemical energy into electricity [4].

c) Inverter

An inverter is an electrical device used to convert direct current (DC) into alternating current (AC). Inverters convert DC from devices such as batteries, solar panels / solar cells into AC. The use of an inverter from a solar power plant (PLTS) is for devices that use Alternating Current (AC). The output voltage can be fixed or variable with a fixed or variable frequency. The variable output voltage can be determined by changing the Direct Current (DC) input output voltage, in which case the gain of the inverter is kept constant[5].

B. Economic Analysis

An analysis to determine the feasibility of an activity to be carried out based on the parameters of total yield, productivity, and economic benefits as a whole is called economic analysis. Economic analysis is necessary to obtain information on the technical, technological and financial aspects of project [11].

Economic analysis is calculated based on financial feasibility parameters that consider the ability of an investment to return the funds used. In financial economic analysis there are several calculation criteria that can be used, including LCOE (Life Cycle Cost), NPV (Net Present Value), IRR (Internal Rate of Return) and Payback period.

a) Levelized cost of energy (LCOE)

Levelized cost of energy (LCOE) represents Life Cycle Cost (LCC) or the total value of investment, operational & maintenance costs, equipment replacement costs, a generating facility based on the present value in one financial cycle and work cycle, then this value is converted in annual installments with adding the calculation of the inflation rate. The biggest energy cost for solar energy lies in the initial investment costs, while O&M costs relative small. This is in contrast to the energy costs of diesel generators where the initial investment costs tend to be small but the O&M costs are large (especially fuel costs)[8].

b) Net Present Value

The Net Present Value (NPV) method is a method that is carried out by comparing the present value of net cash inflows (proceeds) with the present value of outlays. Therefore, to calculate the feasibility of an investment using the NPV method, data on initial cash outflows, future net cash inflows, and the desired minimum rate of return (M. Giatman, 2017). NPV is commonly used to calculate the return on an investment. So that you know whether the value of the investment has a profit or loss[6].

a) Payback Period

The Payback Period (PP) method is a method used to calculate the length of the period required to return the money invested from the annual cash inflows (proceeds) generated by the investment project (M. Giatman, 2017). If the proceeds are the same each year, the Payback Period (PP) of an investment can be calculated by dividing the total investment (outlays) by the annual proceeds [6].

III. RESEARCH METHODOLOGY

Methodology uses to determine the capacity of a solar power plant and determine whether a power plant has advantages or disadvantages. The first is determine the load profile of Kawaluso Island, designing a solar power plant and the second is economic analysis.

A. Load Profile of Kawaluso Island

Currently, the electricity condition on Kawaluso Island consists of a 160-meter Medium Voltage Network, a 1,368-meter Low Voltage Network and one sub station. Currently, Kawaluso Island has a diesel power plant with a capacity of 2 x 100 kW and operates 12 hours per day. The following chart is the Load Profile of Kawaluso Island.

Based on the operating data of the diesel power plant, the daily electricity consumption on the island of Kawaluso around 170 kWh-200 kWh with the peak is 20 kWh.

B. Designing of Solar Power Plant

To design a solar power plant, there are 3 criteria that must be met. Determine the irradiance value, determine the capacity of the solar power plant and calculate the investment capital.

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Based on the operating data of the diesel power plant, the daily electricity consumption on the island of Kawaluso around 170 kWh-200 kWh with the peak is 20 kWh.

**B. Designing of Solar Power Plant**

To design a solar power plant, there are 3 criteria that must be met. Determine the irradiance value, determine the capacity of the solar power plant and calculate the investment capital.

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**Fig 1. Load Profile On Kawaluso Island**
a) Potention of Kawaluso Island

The following table is Based on data from the National Aeronautics and Space Administration (NASA) average irradiance values of Kawaluso Island from 2021-2022.

<table>
<thead>
<tr>
<th>Months</th>
<th>Irradiance value of Kawaluso Island (kWh/m²)</th>
</tr>
</thead>
<tbody>
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<td>4.72</td>
</tr>
<tr>
<td>February</td>
<td>5.33</td>
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<td>March</td>
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<tr>
<td>July</td>
<td>4.93</td>
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<tr>
<td>August</td>
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<tr>
<td>September</td>
<td>5.67</td>
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<tr>
<td>October</td>
<td>5.51</td>
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<tr>
<td>November</td>
<td>5.14</td>
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<tr>
<td>December</td>
<td>4.92</td>
</tr>
<tr>
<td>Annual Average</td>
<td>5.32</td>
</tr>
</tbody>
</table>

b) Capacity of Solar Power Plant

To determine the capacity of the solar power plant, it must know the load requirement of the power plant. To reduce the intermittent effect of output solar power plant, design of solar power plant has an output 15-20 kWh. The rest will be helped by Diesel power plant. After the load requirement is already known, we need to calculated the capacity of the power plant and the total of solar modules.

Power generated when the temperature t°C = 0.35% per°C × P Modules x temperature rise (°C)

Power Generated After temperature rise = P_{when it rises to t°C} - P_{generated when t °C}

From the calculation of the maximum output power of the solar panels when the temperature rises to t°C, the value of the Temperature Correction Factor (TCF) is calculated using the following formula

\[ TCF = \frac{P_{when it rises to 28.6°C}}{P_{Modules}} \]

After the calculation TCF, next is PV Area are used for this Solar power plant.

\[ PV_{Area} = \frac{P}{G_{av} \times \eta_{pv} \times TCF \times \eta_{out}} \]

PV_{Area} = Area of Array (m²)
P = Daily Load (kWh)
G_{av} = Irradiation (kWh/m²)
\eta_{pv} = Efficiency of PV Modules (%)
TCF = Temperature Correction Factor
\eta_{out} = Efficiency of system (%)

Capacity of solar power plant = PV area x Peak Solar Insolation x Efficiency of Solar Modules

The optimal time that can be used for the photovoltaic process is 5 hours. After calculation capacity of solar power plant, next is determine the number of solar panels

Number of panels = \frac{\text{Capacity of Solar Power Plant}}{\text{Capacity of Solar Modules}}

To find out the capacity of the inverter to be used, we will calculate the series-parallel of the solar modules used. The determination of this circuit is carried out to determine the amount of power released by the solar panel as a whole, if to increase the current it is installed in parallel, and if you want to increase the voltage it needs to be arranged in series.

Minimum of series circuit = \frac{\text{Minimum Voltage Inverter}}{\text{Open Circuit Voltage of Solar Panel (Voc)}}

Maximum of series circuit = \frac{\text{Maximum Voltage Inverter}}{\text{Maximum Power Voltage of Solar Panel (Vmp)}}

Maximum of Parallel circuit = \frac{\text{Maximum Power Current Input Inverter}}{\text{Maximum Power Current (Imp)}}

And for the capacity of inverter will arranged by:

Power of inverter > Power of solar modules

Capacity and the numbers of batteries will calculated by:

Total Capacity Battery of system = \frac{\text{Total daily produce of solar energy}}{\text{Day of Discharge x System}}

Number of Battery = \frac{\text{Capacity of each batteries}}{\text{Voltage of System}} \times \frac{\text{Voltage of batteries}}{

Cost of Energy diesel power plant = \text{Capacity of Diesel Power Plant} \times \text{Cost of energy diesel power plant} \times 365 \text{ days}

Cost of energy diesel power plant = \text{Cost of Fuel + Cost of O&M Diesel power plant}

c) Economic Analysis

Calculation of the initial investment cost of PLTS is based on the cost of the components. The initial investment cost for PLTS consists of the cost of PV modules, structures, inverters, installation costs, shipping costs and initial operations. In calculating the initial investment cost of PLTS, it is assumed that US$ 1 is equal to Rp. 15,323 (Oktober 2022)

To know how much cost of energy that we need. First one is we must know the cost operation and maintenance. Operation and Maintenance of solar energy will influence by data of National Renewable Energy cost (NREL). And the diesel will influence by fuel cost and operation cost. After that we need to know about life cycle cost Levelized cost of energy presenting as life cycle cost or total cost from investment capital, operation and maintenance, and cost of equipment change. And then this cost will calculated with interest rate (discount factor and inflation rate). Cost of energy (CoE) is the cost required to generate or produce every 1 kWh of electrical energy. The cost of energy is obtained from the quotient between the annual costs the total energy supplied per year. Cost of energy (CoE) determines a project will be implemented or not.

To arranged the cost of operation and maintenance of solar energy and diesel energy will calculated by:

Annual Cost of O&M Solar Energy = Cost O&M by NREL \times \text{Capacity of Solar Power Plant}

Annual Cost of O&M Diesel Energy = \text{Capacity of Diesel Power Plant} \times \text{Cost of energy diesel power plant} \times 365 \text{ days}

Cost of energy diesel power plant = \text{Cost of Fuel + Cost of O&M Diesel power plant}
PV O&M Hybrid Energy = Annual Cost O&M Hybrid
(Solar/Diesel) Energy \times \left(\frac{1+i}{1+id}\right)^{\left[\frac{(n+1)}{1+id}\right]} \\

PV O&M is Present value of operation and
maintenance as the lifetime. (i) is interest, (d) is
discount factor and (n) is the year of the project
data.

Levelized cost of energy presenting as life cycle cost
or total cost from investment capital, operation and
maintenance, and cost of equipment change. And then
this cost will calculated with interest rate (discount factor
and inflation rate)]. The Life Cycle Cost value will be
calculated based on the following equation.

Life cycle cost (LCC) = C + Mpw + Rpw
(C as the capital of investment and the cost of land
rent. (Mpw) as the Present value of operation and
maintenance of solar and diesel power plant as the
lifetime and (Rpw) as the cost change of equipment on
solar power plant (Cost of change Inverter and battery).

Cost of energy (CoE) is the cost required to generate
or produce every 1 kWh of electrical energy. The cost of
energy is obtained from the quotient between the annual
costs the total energy supplied per year. Cost of energy
(CoE) determines a project will be implemented or not.
The Cost of Energy (CoE) of Hybrid power plant is
calculated by dividing the annual LCC (ALCC) by
Production of electricity. Annual LCC (ALCC) Hybrid
power plant can be calculated using the following
equation.

Annual Life Cycle Cost = LCC \left[\frac{1-(\frac{1+i}{1+id})^{n}}{1-(\frac{1+i}{1+id})}\right] \\\
And the cost of energy will calculated by.
Cost of Energy Hybrid Power Plant =
Annual Life Cycle Cost
Energy Production of Solar Power Plant

Net present value is the cash flow that will counted
after discounted by the interest rate factor.
Cash inflow=

\text{Solar power plant production} \times (\text{COE Hybrid Power Plant + income by 5\% COE}) +
\text{Diesel power plant production} \times (\text{COE Hybrid Power Plant})

Cash Outflow = Annual Cost of O&M Diesel Energy + Annual Cost of O&M Solar Energy

Net Cashflow = Cash Inflow – Cash Outflow

Present Value = (\text{Net Cashflow (1+Discount Factor+Inflation)^n})

Net Present Value = Present Value of years maximum
of project – (Investment Capital + Cost of Land rent)

The value of Internal rate of return will be determined
with the condition NPV = 0. This method using a
approach of value the interest. So we need to know when
the NPV is negative and the NPV is positive.

Payback period is the time required for present value
is higher than investment through income from the
project. After we look the table of Cash Flow then we can
decide the payback period.

Payback Period = \frac{n + a-b}{c-b} \times 1 \text{ year}
(n) is the last year when the cashflow still insufficient of
capital investment. (a) capital investment, (b) is present
value of (n) years. (c) is present value + 1 year.

IV. RESULTS AND DISCUSSION

A. Irradiation Value and Temperature

For the solar irradiance value, the average value for the
area of the kawaluso island will be used, which is 5.32
kWh/m² obtained from data from NASA (National
Aeronautics and Space Administration) or the
Aeronautics and Space Agency.

<table>
<thead>
<tr>
<th>TABLE 2. IRRADIANCE VALUE OF KAWALUSO ISLAND FROM NASA</th>
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<tr>
<td>Months</td>
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<tr>
<td>---------------</td>
</tr>
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<td>November</td>
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<td>December</td>
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<td>Annual Average</td>
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<table>
<thead>
<tr>
<th>TABLE 3 TEMPERATURE OF KAWALUSO ISLAND</th>
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<td>Months</td>
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<tr>
<td>Rata-rata</td>
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<tr>
<td>Maximum</td>
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<tr>
<td>Temperature Ever Recorded</td>
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</table>

B. Capacity of Solar Power Plant

In the electricity system on Kawaluso Island the highest
load can reach 20 kWh at night so it can be assumed that
the highest load is rounded up to 20 kWh. So that the
daily load requirement for Kawaluso Island is.

Daily Load = 20 kWh \times 24 hours = 480 kWh

From temperature data indicates a maximum
temperature increase of 4.36 °C from the standard
temperature of 25°C which is obtained from testing the
specifications of the solar module using the equation
obtained as follows:

\text{Power generated when the temperature } 28°C = 0.35% \text{ per}^\circ \text{C } \times P \text{ Modules } \times \text{ temperature rise}(^\circ \text{C})

\text{Power generated when the temperature } 28°C = 0.35% \text{ per}^\circ \text{C } \times 540W \times 4.36(°C) = 8,2404 W
The maximum output power of solar panels when the temperature rises to 29.36°C, the following formula is used:

\[ P_{\text{when it rises to } 29.36^\circ C} = P_{\text{Modules}} - P_{\text{generated when } 29.36^\circ C} \]

For the first condition, it will calculate the number of panels needed with a load that covers 2/3 of the total load.

Daily load Solar power plant (2/3) = Daily Load x 2/3
= 480 kWh x 2/3 = 320 kWh

The optimal time that can be used for the photovoltaic process is 5 hours so that the amount of power that can be generated is:

\[ \text{PV Area} = \frac{320 \text{ kWh}}{5,32 \text{ kWh/m}^2 \times 0.2094 \times 0.98 \times 0.82} = 357,455 \text{ m}^2 \]

Total Generation from Solar power plant =
357,455 m² × 1000 W/m² × 0.2094 = 74.8 kWp

For the second condition, it will calculate the number of panels needed with the diesel power plant still operating for 24 hours with a limited output of 5 kWh per hour and the rest will be supplied by the solar power plant plus batteries.

Daily Load of Solar power plant (5kWH) = Daily Load – (Generation of Diesel Power Plant x 24 hours)
= 480 kWh – (5 kWh x 24 hours) = 360 kWh

In calculating the number of panels used, there are 2 cases that will be used, namely hybrid solar power plant covering 2/3 of the total load or 16 hours a day. And the condition of PLTD as a follower with a constant 5 kWh load.

**a) Solar Power Plant with 2/3 Daily Consumption**

For the first condition, it will calculate the number of panels needed with a load that covers 2/3 of the total load.

Daily load Solar power plant (2/3) = Daily Load x 2/3
= 480 kWh x 2/3 = 320 kWh

The optimal time that can be used in the photovoltaic process is 5 hours so that the amount of power that can be generated is:

\[ \text{PV Area} = \frac{360 \text{ kWh}}{5,32 \text{ kWh/m}^2 \times 0.2094 \times 0.98 \times 0.82} = 402,138 \text{ m}^2 \]

Total Generation from Solar power plant =
402,138 m² × 1000 W/m² × 0.2094 = 84.3 kWp

So the number of solar panels used if one panel with a size of 540 Wp is

Number of Panels = \[ \frac{\text{Total generation from solar power plant}}{\text{Capacity of solar panels}} \]

Number of Panels = \[ \frac{84.3 \text{ kWp}}{540 \text{ Wp}} \] = 155.93 rounded up to 156 Solar modules

**b) Solar Power Plant with Diesel Power Plant as Base Load.**

The determination of this series-parallel of solar modules is carried out to determine the amount of power released by the solar panel as a whole, if to increase the current it is installed in parallel, and if you want to increase the voltage it needs to be arranged in series.
Minimum of series circuit = 
\[
\frac{\text{Minimum Voltage Inverter}}{\text{Open Circuit Voltage of Solar Panel (Voc)}} = \frac{200 \text{ V}}{49.49 \text{ V}} = 4,049, \text{ rounded to 5 Panels}
\]

Maximum of series circuit = 
\[
\frac{\text{Maximum Power Voltage of Solar Panel (Vmp)}}{\text{Maximum Voltage Inverter}} = \frac{1000 \text{ V}}{40.91 \text{ V}} = 24.44, \text{ rounded to 25 Panels}
\]

Maximum of Parallel circuit = 
\[
\frac{\text{Maximum Power Current Input Inverter}}{\text{Maximum Power Current (Imp)}} = \frac{260 \text{ A}}{13.2 \text{ A}} = 19.69, \text{ rounded to 20 Panels}
\]

- **Series-Parallel Modules of 74.8 kWp**

Based on the results of the calculation of the number of modules, the number of modules is 139 modules. So that the calculation of the voltage can be in accordance with the capacity of the inverter used, it can be calculated that the number of solar panels will be added by 5 panels where each segment can be arranged in 18 modules in series and 8 modules in parallel. The module requirements used are in accordance with the inverter input requirements. Then the current and voltage calculations are obtained as follows:

Total Current of circuits = Maximum Power Current (Imp) x Number of Parallel Modules
= 13.2 A x 8 units
= 104 A

Total Voltage of circuits = Maximum Power Voltage x Number of Series Modules
= 40.91 x 18 units
= 736.38 V

- **Series-Parallel modules 84.3 kWp**

Based on the results of the calculation of the number of panels, the number of solar modules is 156. So that the calculation of the voltage can be in accordance with the capacity of the inverter used, it can be calculated that the number of solar panels will be added by 6 panels to 162 panels. Then the current and voltage calculations are obtained as follows:

Total Current of circuits = Maximum Power Current (Imp) x Number of Parallel Modules
= 13.2 A x 9 units
= 118.8 A

Total Voltage of circuits = Maximum Power Voltage x Number of Series Modules
= 40.91 x 18 units
= 736.38 V

d) **Area of Array**

The location of the Solar power plant will be close to the diesel power plant area. After knowing the number of solar modules to be installed, it is necessary to calculate the total area that will be used for module installation.

- **Area of Array Solar Power Plant 74.8 kWp**

Area of Array Solar Power Plant 74.8 kWp = (Total Length of Modules x Total width of Modules) + Buffer Zone 30%
= (2274 mm x 8 pieces + 1134 mm x 18 pieces) + 30%
= 482.62 m²

- **Area Of Array Solar Power Plant 84.3 kwp**

Area of Array Solar Power Plant 84.3 kWp = Total Length of Modules x Total width of Modules + Buffer Zone 30%
= 2274 mm x 9 pieces + 1134 mm x 18 pieces + 30%
= 542.85 m²

C. **Batteries**

The battery used is a lead acid type battery with a nominal capacity of 100 Ah, so that the usable capacity is obtained by the following equation.

\[
\text{Total Capacity of system} = \frac{\text{Total daily produce of solar energy}}{\text{Day of Discharge x System}}
\]

Total Capacity of 74.8 kWp = 320 kWh/day
80% x 480 VDC = 833.33 Ah

Total Capacity of 84.3 kWp = 360 kWh/day
80% x 480 VDC = 937.5 Ah

After calculating the capacity, it will be followed by calculating the number of batteries that you want to use in planning.

Number of Battery = Total Capacity Battery of system x \( \frac{\text{Capacity of each batteries}}{\text{Voltage of System}} \)

Number of Battery 74.8 kWp = \( \frac{833.33}{100} \times 480 \) = 333.32 pcs, rounded to 334 Batteries

Number of Battery 84.3 kWp = \( \frac{937.5}{100} \times 480 \) = 375.15 pcs, rounded to 376 Batteries

D. **Inverters**

For the calculation results, the number of solar modules of 74.8 kWp used is 144 modules and the voltage is 736.38 V. Based on the data sheet from the inverter to be used, the minimum input voltage is 200 Volts to 1000 Volts. So that the required inverter is 1 inverter. The inverter used has a capacity of 75 kW so that it meets the requirements for an inverter.

For the calculation results of 84.3 kWp solar power plant, the number of solar modules used is 162 modules and the voltage is 736.38 V. Based on the data sheet from the inverter to be used, the minimum input voltage is 200 Volts to 1000 Volts. So that the required inverter is 1 inverter with a capacity of 90 kW.

E. **Investment Capital**

Investment capital of 74.8 kWp Solar power plant

<table>
<thead>
<tr>
<th>Component</th>
<th>Amount</th>
<th>Price by Pieces (Rp)</th>
<th>Total Prices (Rp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Panel</td>
<td>144</td>
<td>Rp3.500.000</td>
<td>Rp. 504.000.000</td>
</tr>
<tr>
<td>Jinko Solar 540Wp</td>
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</tbody>
</table>
Battery 12 V 100 Ah 334 Rp2.300.000 Rp.768.200.000
Inverter 75 kW (Huawei) 1 Rp. 86.500.000 Rp. 150.000.000
Mounting of Solar Panels 144 Rp.500.000 Rp. 72.000.000
Cost of Installation 1 Rp. 100.000.000 Rp. 100.000.000
Cost of First Operation 74.8 kWp Rp.20.000.000 Rp. 20.000.000
Transportation cost 1 Rp.200.000.000 Rp. 200.000.000
Investment Capital Rp. 1.814.200.000

Investment Capital of 84,3 kWp Solar Power Plant

<table>
<thead>
<tr>
<th>Component</th>
<th>Amount</th>
<th>Price by Pieces (Rp)</th>
<th>Total Prices (Rp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Panel, Jinko Solar 540Wp</td>
<td>162</td>
<td>Rp 3,500.000</td>
<td>Rp 567,000.000</td>
</tr>
<tr>
<td>Battery, Lifepod 12 V 100 Ah</td>
<td>375</td>
<td>Rp2,300.000</td>
<td>Rp 862,500.000</td>
</tr>
<tr>
<td>Inverter 90 kW (Huawei)</td>
<td>1</td>
<td>Rp.150.000.000</td>
<td>Rp. 150,000.000</td>
</tr>
<tr>
<td>Mounting of Solar Panels</td>
<td>162</td>
<td>Rp.500.000</td>
<td>Rp. 81,000.000</td>
</tr>
<tr>
<td>Cost of Installation</td>
<td>1</td>
<td>Rp.100.000.000</td>
<td>Rp. 100,000.000</td>
</tr>
<tr>
<td>Cost of First Operation 74.8 kWp</td>
<td>72</td>
<td>Rp. 20,000.000</td>
<td>Rp. 20,000.000</td>
</tr>
<tr>
<td>Transportation cost</td>
<td>1</td>
<td>Rp.200,000.000</td>
<td>Rp. 200,000.000</td>
</tr>
<tr>
<td>Investment Capital</td>
<td></td>
<td></td>
<td>Rp. 1,980,500.000</td>
</tr>
</tbody>
</table>

F. Operation and Maintenance Cost

The following is the cost of operation and maintenance of 74.8 kWp and 84.3 kWp solar power plant.

Annual cost O&M Solar Power Plant 74.8 kWp =
USD 17.10 x 74.8 kWp
= USD 1.279.08 /year = Rp. 19.477.830,24 /year
Annual cost O&M Solar Power Plant 72 kWp =
USD 17.10 x 84.3 kWp
= USD 1.441,53 /year = Rp. 21.951.618,84 /year

With fuel cost Rp. 24.550/ liter and a Specific fuel consumption of State electricity company (PLN) Diesel Power Plant 0.422 litre / kWh, the fuel cost of diesel power plant can be calculated with the following equation:

Cost of diesel power plant = Cost of fuel per liter x SFC Diesel power plant
= Rp. 24.550 /lr x 0.422 ltr/kWh = Rp. 10.360,1/kWh

The Cost O&M of diesel power plant as the base load is assumed to be Rp.400/kWh consisting of employee costs, spare parts and lubricants. So that the energy costs of PLTD PLN can be calculated by the following equation.

\[ C_{\text{O&M}} = (1 + \frac{i}{1 + d}) \left(\frac{1 - \left(1 + \frac{i}{1 + d}\right)^n}{1 - \left(1 + \frac{i}{1 + d}\right)^0}\right) \]

\[ = (1 + \frac{0.0571}{1 + 0.0475}) \left[\frac{1 - \left(1 + \frac{0.0571}{1 + 0.0475}\right)^{25}}{1 - \left(1 + \frac{0.0571}{1 + 0.0475}\right)^0}\right] \]

\[ = \text{Rp.} 549.447.870,6 \]

O&M Diesel PW = (O&M/ Year) \times \left(\frac{1}{1 + d}\right) \left[\frac{1 - \left(1 + \frac{i}{1 + d}\right)^n}{1 - \left(1 + \frac{i}{1 + d}\right)^0}\right]

Cost Of Energy Diesel Power Plant = Cost of diesel power plant + Cost of O&M PLTD PLN = Rp. 10.360,1 /kWh + Rp. 400/kWh = Rp. 10.760,1 /kWh

Annual Cost of Diesel Power plant 1/3 Load = 160 kWh x 1 year x Rp. 10.760,1 = Rp 619.781.760 /year
Annual Cost of Diesel Power plant as base Load = 120 kWh x 1 year x Rp. 10.760,1 = Rp 464.836.320 /year

\[ C_{\text{O&M}} = \left(1 - \frac{1}{(1 + \frac{i}{1 + d})^n}\right) \times \frac{1}{1 - \left(1 + \frac{i}{1 + d}\right)^0} \]

\[ = \text{Rp.} 549.447.870,6 \]

\[ \text{O&M Diesel PW} = \left(\text{O&M/ Year}\right) \times \left(\frac{1}{1 + d}\right) \left[\frac{1 - \left(1 + \frac{i}{1 + d}\right)^n}{1 - \left(1 + \frac{i}{1 + d}\right)^0}\right] \]
The cost of replacing the 74,8 kWp and 84,3 kWp Solar power plant inverter for the 5th, 10th, 15th and 20th year is assumed to be the same price as the current inverter price. The present value of costs that will be incurred to replace the inverter in years 5, 10, 15 and 20 can be calculated using the following equation:

$$C_{eq} (n) = C_{eq} \left( \frac{1 + \frac{r}{d}}{1 + \frac{r}{d}} \right)^n$$

$$C_{eq} (5) = Rp. 150.000.000 \times \left( \frac{1 + \frac{0.0571}{0.0475}}{1 + \frac{0.0571}{0.0475}} \right)^5 = Rp. 131.125.514.200$$

The cost of replacing the 74,8 kWp and 84,3 kWp Solar power plant battery for the 5th, 10th, 15th and 20th year is assumed to be the same price as the current battery price. The present value of costs to be incurred for battery replacement in years 5, 10, 15, and 20 can be calculated using the following equation:

$$C_{eq} \text{ in year } 5 = Rp. 157.000.655$$

$$C_{eq} \text{ in year } 10 = Rp. 164.328.032$$

$$C_{eq} \text{ in year } 15 = Rp. 171.597.398$$

$$C_{eq} \text{ in year } 20 = Rp. 180.024.494$$

$$C_{eq} \text{ in year } 25 = Rp. 673.350.785$$

The Life Cycle Cost value for a 74,8 kWp and 84,3 kWp solar power plant can be calculated based on the following equation:

$$\text{LCC}_{74.8 \text{ kwp hybrid}} = C + Mwp + Rpw$$

$$= (Rp. 6.591.781.760 + (1 + \frac{0.0571}{0.0475})^{25} - 1 \left( \frac{1 + \frac{0.0571}{0.0475}}{1 + \frac{0.0571}{0.0475}} \right)^{25}) = Rp. 17.483.352.300$$

O&M Solar 74,8 kWp PW = (O&M/Year) ×

$$\left( \frac{1+\frac{r}{d}}{1+\frac{r}{d}} \right)^n$$

$$= (Rp. 21.951.618.84) \times \left( \frac{1 + \frac{0.0571}{0.0475}}{1 + \frac{0.0571}{0.0475}} \right)^5 = Rp. 619.230.688.4$$

O&M PLTD PW = (O&M/ Year) ×

$$\left( \frac{1+\frac{r}{d}}{1+\frac{r}{d}} \right)^n$$

$$= (Rp. 464.836.320) \times \left( \frac{1 + \frac{0.0571}{0.0475}}{1 + \frac{0.0571}{0.0475}} \right)^5 = Rp. 13.112.514.200$$

$$\text{LCC}_{84.3 \text{ kwp hybrid}} = C + Mwp + Rpw$$


### H. Cost of Energy

The Energy Cost (COE) of PLTS On Grid is calculated by dividing the annual LCC (ALCC) by the plant's annual electricity production. Annual LCC (ALCC) PLTS Hybrid 64 kWp and 72 kWp can be calculated using the following equation:

$$\text{ALCC}_{64 \text{ kwp}} = \text{LCC}_{74.8 \text{ kwp hybrid}} \times \left( \frac{1 + \frac{r}{d}}{1 + \frac{r}{d}} \right)^5$$

$$= Rp. 24.263.590.780.60 \times \left( \frac{1 + \frac{0.0571}{0.0475}}{1 + \frac{0.0571}{0.0475}} \right)^5 = Rp. 868.022.925$$

$$\text{ALCC}_{84.3 \text{ kwp hybrid}} = \text{LCC}_{84.3 \text{ kwp hybrid}} \times \left( \frac{1 + \frac{r}{d}}{1 + \frac{r}{d}} \right)^5$$

$$= Rp. 20.570.217.688.40 \times \left( \frac{1 + \frac{0.0571}{0.0475}}{1 + \frac{0.0571}{0.0475}} \right)^5 = Rp. 735.893.574$$

$$\text{COE} = \frac{\text{Annual LCC}}{\text{Annual kWh}}$$

$$\text{COE}_{74.8 \text{ kwp}} = \frac{Rp. 868.022.925}{116.800 \text{ kWh/tauhan}} = Rp. 7.432 / \text{kWh}$$

$$\text{COE}_{84.3 \text{ kwp}} = \frac{Rp. 735.893.574}{131.400 \text{ kWh/tauhan}} = Rp. 5.601 / \text{kWh}$$

### I. Net Present Value

It is assumed that the electrical energy produced by the Solar Power Plant experiences a depreciation of 2% each year. The investment and land rental costs for Solar Power Plant 74.8 kWp and 84.3 kWp are Rp. 2.108.986.000 and Rp 2.293.355.000 with a total electrical energy generated by Solar power plant 74.8 kWp and 84.3 kWp per year of 116,800 kW/h/year and 131,400 kW/h/year then it is assumed that the desired profit is 5%, then cash inflows are calculated based on the following equation:

$$\text{Cash Inflow} = \text{Solar Energy} \times (\text{COE}_{74.8 \text{ kwp}} + \text{profit} 5\%) + \text{Diesel Energy \times (COE}_{74.8 \text{ kwp}} \text{ + profit} 5\%)$$

$$= 116.800 \text{ kWh/year} \times (\text{Rp. 7.432 / kWh} + \text{Rp. 371}) + 58.400 \text{ kWh/year} \times \text{Rp. 7.432 / kWh}$$

$$= 1.345.489.280$$

$$\text{Cash Inflow} = \text{Solar Energy} \times (\text{COE}_{84.3 \text{ kwp}} + \text{profit} 5\%) + \text{Diesel Energy \times (COE}_{84.3 \text{ kwp}} \text{ + profit} 5\%)$$

$$= 131.400 \text{ kWh/year} \times (\text{Rp. 5.601 / kWh} + \text{Rp. 280}) + 43.800 \text{ kWh/year} \times \text{Rp. 5.601} = \text{Rp. 1.018.093.770}$$

Meanwhile, the cash outflow each year can be calculated based on the annual costs of O&M Solar Power Plant and O&M Diesel power plant, with O&M solar power plant Rp. 19.477.830.24 and Rp.

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21.951.618,84. O&M Diesel power plant of Rp. 619.781.760 dan Rp. 464.836.320 and in the 5th, 10th, 15th and 20th year the cash outflow is added to the cost of replacing equipment such as inverters and batteries. Net Cash Flow is calculated based on the following equation:

\[
\]


Present Value (Net Cashflow) 74,8 kWp = \[
\frac{74,8}{(1+\text{Discount Factor}+\text{Inflation})^n} = \frac{74,8}{1.05\times\text{Discount Factor}+\text{Inflation}} = \frac{74,8}{1+(4.75\%+5.71\%)}^3 = \frac{74,8}{1.75\times\text{Discount Factor}+\text{Inflation}} = \frac{74,8}{1+1.75\%} = \frac{74,8}{1.018.093.770 + Rp. 21.951.618,84 + Rp. 464.836.320) = Rp. 531.305.831,16
\]

Present Value (Net Cashflow) 84,3 kWp = \[
\frac{84,3}{(1+\text{Discount Factor}+\text{Inflation})^n} = \frac{84,3}{1+\text{Discount Factor}+\text{Inflation}} = \frac{84,3}{1+(4.75\%+5.71\%)}^3 = \frac{84,3}{1.75\%} = \frac{84,3}{1+1.75\%} = \frac{84,3}{1.018.093.770 + Rp. 21.951.618,84 + Rp. 464.836.320) = Rp. 531.305.831,16
\]

Payback Period

\[
\text{Payback Period} = \frac{n + \frac{a-b}{c-b}} \times 1 \text{ year} = \frac{3 + \frac{1.814.200.000-Rp. 1.700.441.934.36}{Rp. 2.138.017.050.06-Rp. 1.700.441.934.36}} \times 1 \text{ year} = 3 \text{ years and 2 months}
\]

\[
\text{Payback Period} = \frac{n + \frac{a-b}{c-b}} \times 1 \text{ year} = \frac{8 + \frac{1.980.500.000-Rp. 1.970.011.517.54}{Rp. 2.139.924.700.74-Rp. 1.970.011.517.54}} \times 1 \text{ year} = 8 \text{ years, 1 month}
\]

V. CONCLUSION

For the initial investment value of Solar Hybrid Power Plant on Kawaluso Island with the calculation method is Rp. 1.814.200.000 with a capacity of 74,8 kWp and Rp. 1.980.500.000 with a capacity of 84,3 kWp.

Based on theoretical calculations, the cost of energy obtained by the 74,8 kWp Hybrid power plant is Rp. 7.432 with a positive NPV value of Rp. 1.678.249.973,06 so the investment is feasible. For the calculation of the cost of energy with a 84,3 kWp hybrid PLTS capacity, it is Rp. 5.601 with a positive NPV value of Rp. 682.319.021,55 so that the project is feasible to run.

The payback period for a 74,8 KWP hybrid PLTS takes 3 years 2 months and 8 years and 1 months for a 84,3 KWP PLTS capacity.

REFERENCES


