# Benefit Optimization and Energy - Economy Environmental Analysis of Solar Rooftop Photovoltaic System at Industrial Segment in Indonesia

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***Abstract* – This study aims to compare 4 scenarios of solar rooftop photovoltaic system technology that is used in the industrial segment in two different locations in Indonesia. Comparisons were made using energy, economic and environmental analysis methods and continued with optimization using linear programming methods. The results of the study show that scenario 2 solar photovoltaic system can produce more electrical energy and $CO_2$ that can be reduced than in the other scenarios. While scenario 4 solar photovoltaic system is a scenario with better economic value and optimal benefits value than the other scenarios.**

***Keywords* – energy economic and environmental analysis, linear programming, renewable energy, solar rooftop photovoltaic system.**

## 1. Introduction

Indonesia has a variety of renewable energy potential that is very abundant. In total, the potential for renewable energy in Indonesia reaches 442 GWp but its utilization is still very minimal, which is 9.5 GWp or about 2.15% of the total potential [18].

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One type of utilization of solar energy in Indonesia is through Solar Power Plants (PLTS). In total, the installed capacity of PLTS until 2020 is only 181.2 MWp, very far from the National Energy General Plan or RUEN [25] target of 900 MWp [13]. Solar rooftop photovoltaic (PV) systems are one of the most popular types of PLTS in Indonesia today. Based on data from 2019 to October 2020, the growth in the installed capacity of solar rooftop PV systems has almost doubled. Solar rooftop PV systems grew from 16.66 MWp in 2019 to 30.38 MWp in 2020 [13]. Based on IESR 2021 data, the industrial segment is the segment with the largest installed solar rooftop PV systems capacity in 2020. In 2020 the industrial segment contributed 8 MWp of Solar rooftop photovoltaic systems installed capacity [13].

Several factors have caused the use of solar rooftop PV systems in the industrial segment to increase in Indonesia, including:

a. Load profile and industrial location, infrastructure readiness, and expertise.
b. Potential savings and carbon tax policies. This policy is contained in Law number 7 of 2021 article 13 [15] regarding the harmonization of tax regulations. It is also written in Presidential Regulation number 98 of 2021 [26] regarding the implementation of Carbon Economic Value (NEK)
c. PAS 2060 Carbon Neutral and Net Zero Emission (NZE) certification.

The development of solar panel technology is increasing nowadays. Many choices of types of solar panels are offered with different types [20], power and efficiency levels of solar cell technology [33]. This raises the question of how to choose the right solar PV system technology for the industrial segment with optimal benefits. This problem is in line with the conclusions of previous studies which said that research on the installation, optimization, and evaluation of solar photovoltaic cases in certain places in Indonesia would be interesting to do as further research [16]. Other studies also mention that optimizing the cost of solar PV systems with objects other than houses with different attributes can be used as a topic for further research [17]. Previous research on the techno-economic analysis of solar rooftop PV systems on new industrial buildings was conducted in Egypt [12] and Uganda [21]. A comparison of the techno-economic analysis of PV module technology has also been carried out but only in the residential segment in Colombia [22] and Semarang, Indonesia [34], as well as the commercial segment in Hong Kong [29] and public facility buildings [36]. In addition, there is also a study that compares the techno-economic analysis of solar panel technology on several types of cooling systems for floating PV systems in Taiwan [6]. Finally, a study comparing techno-economic analysis on a solar rooftop PV system was also conducted by comparing 7 scenarios of government policies and 2 models of ownership of fish storage refrigeration warehouses in Indonesia [28].

This study aims to compare the types of solar photovoltaic system technology in the industrial segment in Indonesia for 25 years of operation. Comparisons were made using energy, economic and environmental analysis methods [27] and continued with optimization using linear programming methods [35]. Optimization is carried out to find the optimum benefit value that can be obtained from all scenarios of the solar rooftop PV system. The benefits referred to in this study consist of 3 parts, which are the benefits of electrical energy produced, benefits in terms of economic value, and environmental benefits.

This research will use a case study of solar rooftop PV systems for the industrial segment in Indonesia. The case study occurred in one of the multinational soft drink companies in Indonesia. The company commits to using environmentally friendly energy or new renewable energy in their manufacturing facilities. The renewable energy source chosen by the company is solar energy by installing a solar rooftop PV system. As a multinational company with its head office in Europe, the company has its internal policy targets regarding the use of renewable energy. The parent company has targeted all of its manufacturing facilities with Net Zero by 2040 and certified Carbon Neutral with the International Standard PAS 2060. Besides the internal policy target, the company also prepares for the implementation of the Indonesian government policy regarding the Carbon Economic Value (NEK) or carbon tax regulations.

## 2. Literature Review

### A. *Energy Analysis*

Energy consumption is the amount of energy (electricity) used in buildings or facilities to support or carry out daily activities according to their respective goals. Energy consumption data can be obtained from several sources, including monthly electricity bills, maximum power demand, or recorded power meters (Paudel et al., 2021)[24].

The electrical energy potential (Energy output) of solar rooftop PV systems is calculated based on solar radiation data [24]. Common sources of solar irradiance data for a given location can be obtained through the nearest meteorological station and from online databases such as Meteonorm [24]. The maximum roof surface area that can be used to install solar panels on industrial buildings is 80% of the total available roof area [21]. Calculation of the energy potential of rooftop solar panels by using the surface area [10] of solar cells by using the following formula:

$$E_{out} = A \times \eta \times H \quad (1)$$

Where $E_{out}$ (Energy output) is the electrical energy that can be generated by solar rooftop PV systems (kWh). A is the total solar panel area (m2). $\eta$ is conversion efficiency (%) and H is solar radiation at a certain location (Wh/m2). Solar radiation data regarding the electrical energy potential of solar rooftop PV systems in this study were taken directly through a pyranometer sensor that has been installed and operated for 1 year of observation and taken from the Meteonorm online database. Several studies were researched to measure the electrical energy potential of solar rooftop PV systems in various countries including India [7], Nepal [24], Hongkong [29], Bangladesh [5], Turkey [8], Egypt [9], Maldives [2], Thailand [30], and Brazil [19].

### B. *Economy Analysis*

Net Present Value (NPV) can be defined as the difference between the net cash flows in and the net cash flows out for a certain period by taking into account the prevailing bank interest rates [23]. Where the NPV value of a project is said to be profitable if it has an NPV value > 0 which is calculated by the following formula [8]:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0 \quad (2)$$

Where $C_t$ is net cash flow in period t, $C_o$ is initial investment cost, T is projected lifetime, and r is the discount rate.

Levelized Cost of Energy (LCOE) is the cost incurred by a power plant to produce electrical energy per kWh [4]. In simple terms, LCOE can be formulated as follows [27]:

$$LCOE = \frac{\left[\left(\sum_{t=0}^{N} Ct\right)/(1+r)\hat{}t\right]}{\left[\left(\sum_{t=0}^{N} Er\right)/(1+r)\hat{}t\right]} \quad (3)$$

Where $C_t$ is the net cost of the project for time t (including initial investment, operating, and maintenance costs), $E_r$ is the solar energy produced in kWh, N is the life of the project in years and r is the discount rate.

Pay Back Period (PBP) is simply the length of time the return on invested capital is spent to implement a project, Mathematically, the PBP calculation can be written as follows [23]:

$$PBP = \frac{InitialInvestment\ (Cost)}{Revenue\ generated\ per\ year} \quad (4)$$

The Benefit-Cost Ratio (BCR) can be interpreted as a comparison value between the benefits that can be generated by a project compared to the costs incurred for working on the project itself. The calculation of the BCR value mathematically can be written as the following formula [23]:

$$BCR = \frac{Present\ Worth\ Benefit\ (PWB)}{Present\ Worth\ Cost\ (PWC)} \quad (5)$$

The rate of return or Internal Rate of Return (IRR) is the interest rate that can produce the same value between costs or investments with revenues. It is also defined as an interest rate equivalent to the NPV value = 0. The IRR calculation is based on the calculation of Present Value and Annual Value. The calculation of the IRR value can be done by interpolation [1] using the following formula:

$$IRR = Ir + \frac{NPV\ Ir}{(NPV\ Ir - NPV\ It)}\ (It - Ir) \quad (6)$$

Where $I_r$ is a lower interest rate, $I_t$ is a higher interest rate. $NPV\ I_r$ is the net present value at a low-interest rate and $NPV\ I_t$ is the net present value at a high-interest rate.

### C. Environmental Analysis

The current $CO_2$ emissions are a side effect of using non-renewable energy to generate electricity. Calculation of the amount of $CO_2$ that can be reduced through the use of solar energy or PV systems can be done using the following calculation formula [32]:

$$ER_t = EG_t \times EF_{Grid} \quad (8)$$

Where $ER_t$ is the $CO_2$ emission reduction in year t ($tCO_2eq$/year), $EG_t$ is the amount of electricity generated by solar rooftop PV system in year t (MWh/year) and $EF_{Grid}$ is the emission factor for grid-connected power plants ($tCO_2$ / MWh)

### D. Linear Programming

Linear programming is concerned with explaining the real world as a mathematical model consisting of an objective function, decision variables, constraint functions, and formulas for constrained variables. Previous research used linear programming on the solar rooftop PV system, which is research on optimizing the selection of household appliances and the selection of solar rooftop PV systems for households. [17]. Another research is on optimizing the size and arrangement of solar photovoltaic energy storage batteries in multi-apartment buildings using multi-objective Mix Integer Linear Programming [3]. In addition, there is also research on the optimization of Levelized Cost of Energy (LCOE) on a solar rooftop photovoltaic system using 7 scenarios of government policies in fish storage refrigeration warehouses in Indonesia [31].

## 3. Research Methodology

The data used in this study consisted of two types, primary and secondary data. Primary data were obtained by conducting surveys and interviews in the two case study locations, Bekasi and Semarang. Meanwhile, secondary data was obtained through data requests to the company where the case study was conducted. The data used in this study is divided into 4 types of data, which are technical data, energy data [24], economic data [11], and environmental data. Technical data consists of technical data on manufacturing facilities (location, layout, and roof area) and photovoltaic system specification data for each scenario. Energy data consists of potential energy output generated by the solar rooftop PV system and data on electrical energy consumption. The economic data that will be collected in this study include direct capital costs, indirect capital costs, operational and maintenance costs of the solar rooftop PV system. Finally, environmental data includes data on the amount of electrical energy produced by solar rooftop PV systems which are converted into units of tonne $CO_2$ equivalent ($tCO_2eq$).

The data that has been collected is then processed using the energy, economic and environmental analysis method. Meanwhile, specifically for the Bekasi case study, data processing was continued by optimizing using the Linear Programming Method [35]. This is done because the Solar PV system in the Bekasi case study is an existing PV system, and wants to be optimized by maximizing the available roof area up to 80% [21] of the total available roof area to install a solar PV system. Meanwhile, the Semarang case study is a case study of a solar PV system that is still in the planning stage, and it is planned to build a solar PV system covering an area of 80% of the total available roof area.

## 4. Results

All the scenarios specification of the photovoltaic system used in this research can be seen in Table 1, where Bekasi and Semarang's case studies used the Grid-connected PV system scheme [14]. The difference between the two solar rooftop PV systems lies in the capacity of the system. Case study Bekasi has a solar rooftop PV system with a capacity of 7,134 MWp, the same for three other scenarios. This is because the rooftop solar power plant in Bekasi has been installed and operating since 2020 with a PV system capacity of 7,134 MWp. The existing solar rooftop PV system at Bekasi itself uses scenario 1 PV system in Table 1 with a total roof area used of 37,257 $m^2$ of the total 72,000 $m^2$ available roof area or about 51.74%. Meanwhile, the Semarang case study has different capacities for each scenario. This is because the solar rooftop PV system in Semarang will only be built in 2022. Solar rooftop PV system construction is planned to be built by utilizing the available roof area as much as 80% of the available roof area [21]. The total roof area available in Semarang is 25,500 $m^2$, but only 13,700 $m^2$ is suitable for installing a solar rooftop PV system, due to the lifespan of more than 30 years and the condition is no longer possible to accept additional loads from solar panels.

The first analysis result of solar rooftop photovoltaic system scenarios is the energy analysis. From the analysis of the potential electrical energy that can be generated by the solar rooftop photovoltaic system at Bekasi (Figure 1) and Semarang (Figure 2) case study for 25 years of operation, it shows that scenario 2 is the scenario that can produce the most electrical energy compared to other scenarios. In total, scenario 2 is capable of producing 195 GWh of electrical energy in the Bekasi case study and as much as 83 GWh in the Semarang case study for 25 years of operation.

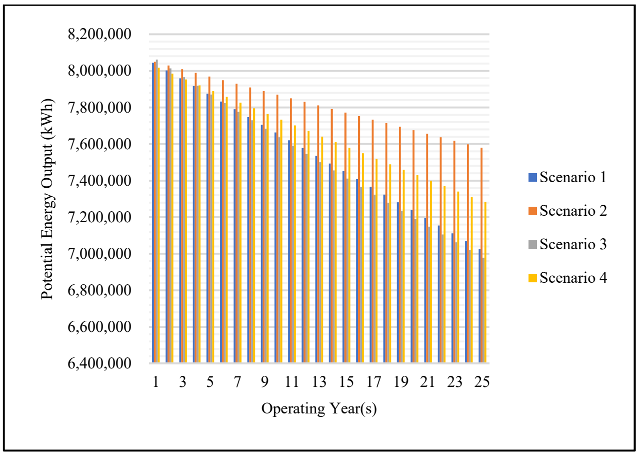


*Figure 1. Potential electrical energy output (kWh) of Bekasi case study solar rooftop PV system*

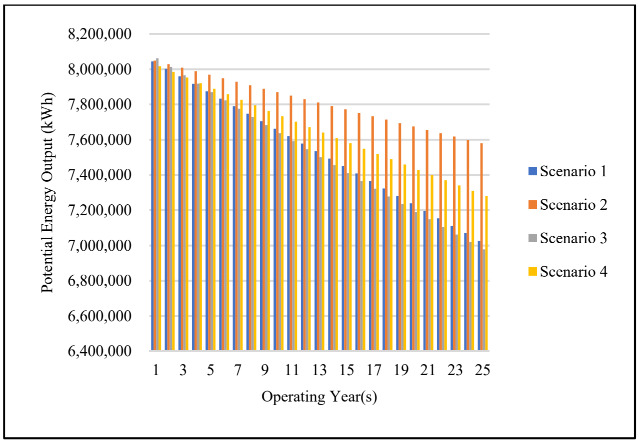


*Figure 2. Potential electrical energy output (kWh) of Bekasi case study solar rooftop PV system*

The second analysis result of solar rooftop photovoltaic system scenarios is the economic analysis. The economic data that has been obtained will be used to perform an economic analysis with several parameters, Net Present Value, Levelized Cost of Energy, Pay Back Period, Benefit-Cost Ratio, and Internal Rate of Return. The calculation is carried out during the life of the solar rooftop PV systems, which is 25 years of operation. The results of the overall economic analysis can be seen in Table 2. From Table 2 it can be seen that scenario 4 of the solar rooftop photovoltaic system is a scenario that has better economic value than the other scenarios in the two case studies.

The last analysis result of solar rooftop photovoltaic system scenarios is the environmental analysis. The environmental analysis was carried out after the analysis of the electrical energy potential of the solar rooftop PV systems was completed. The environmental analysis uses the energy conversion factor ($EF_{Grid}$) to calculate the amount of reduced $CO_2$ emissions based on the Letter of the Minister of Energy and Mineral Resources of Indonesia No. 3783/21/600.5/2008, which is 0.891 kg $CO_2$/kWh.

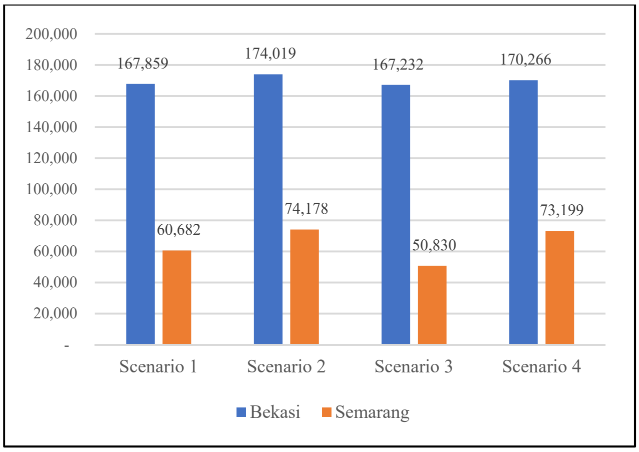


*Figure 3. Potential electrical energy output (kWh) of Bekasi case study solar rooftop PV system*

*Table 1. Scenario specification of solar rooftop photovoltaic system*

| Scenario | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| PV Modul | SPR-P19-395 COM | SPR-X22-485 COM | SPR-P17-330 COM | RSM132-8-680N-700N |
| Nominal Power | 395 W | 485 W | 330 W | 700 W |
| Power Tolerance | +5 / -0% | +5 / 0% | +5 / -0% | +5 / -0% |
| Efficiency | 19.10% | 22.40% | 16.00% | 22.50% |
| Solar cells type | Monocrystalline PERC | 128 Monocrystalline Maxeon Gen III | Multicrystalline cells | Monocrystalline cells |
| Dimension (L x W) | 2067 mm x 998 mm | 2067 mm x 1046 mm | 2067 mm x 998 mm | 2384 mm x 1303 mm |
| Perf. Degradation | 0.6% per year | 0.25% per year | 0.6% per year | 0.4% per year |
| Lifetime warranty | 25 years | 25 years | 25 years | 25 years |
| Inverter type | SMA solid Q-50 | SMA solid Q-50 | SMA solid Q-50 | SMA solid Q-50 |
| Max Efficiency | 98.30% | 98.30% | 98.30% | 98.30% |

*Table 2. Economic analysis result of solar rooftop PV system scenarios at Bekasi and Semarang case studies*

| Item | Bekasi | | | |
|---|---|---|---|---|
| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
| NPV, (USD) | 175,256 | 246,062 | -359,847 | 1,910,663 |
| LCOE, (USD / kWh) | 0.086 | 0.085 | 0.092 | 0.065 |
| PBP, (Year) | 10.79 | 10.8 | 11.7 | 7.83 |
| BCR | 1.02 | 1.03 | 0.95 | 1.36 |
| IRR, (%) | 8.34 | 8.46 | 7.4 | 12.55 |
| Item | Semarang | | | |
| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
| NPV, (USD) | 422,012 | 550,211 | 228,943 | 1,150,768 |
| LCOE, (USD / kWh) | 0.074 | 0.073 | 0.079 | 0.056 |
| PBP, (Year) | 9.07 | 9.05 | 9.77 | 6.47 |
| BCR | 1.19 | 1.21 | 1.12 | 1.58 |
| IRR, (%) | 10.55 | 10.68 | 9.53 | 15.47 |

*Table 3. Energy, economic, and environmental analysis result of Bekasi case study for the optimization model*

| Scenario | ET (kWh / kWp) | $CO_2$ reduction (USD/kWp) | CD (USD/kWp) | CID (USD/kWp) | CO (USD/kWp) |
|---|---|---|---|---|---|
| Scenario 1 | 11,515 | 21.53 | 718.33 | 121.94 | 146.78 |
| Scenario 2 | 11,800 | 22.07 | 752.73 | 100.49 | 151.12 |
| Scenario 3 | 11,490 | 21.49 | 767.52 | 144.70 | 146.34 |
| Scenario 4 | 11,611 | 21.71 | 533.39 | 71.58 | 148.35 |

The results of the analysis show that scenario 2 is a scenario that can reduce the amount of $CO_2$ emissions from the use of solar rooftop PV systems for 25 years of operation. In the case study of Bekasi, scenario 2 can reduce the amount of $CO_2$ emissions by 174,019 $tCO_2eq$. While in the case study of Semarang, scenario 2 can reduce the amount of $CO_2$ emissions by 74,178 $tCO_2eq$.

Optimization of solar rooftop PV systems is carried out to find the optimum benefits value of solar rooftop PV systems in this study. Optimization is carried out using the Linear Programming method by combining the scenarios of the solar rooftop PV systems. The mathematical model used in this study is to maximize the total benefit ($B_T$) of the solar rooftop PV systems in the Bekasi case study. Where the roof area in the Bekasi case study can still be maximized to 80% of the current 51.74%. The mathematical model used in this study is shown in the following objective function:

$$\text{Max } B_T = \sum_i^I \sum_n^N \left((E_{in} + T_{in}) - (C_{in} + CO_{in}).x_{in}\right) \quad (9)$$

Where:

$$E_{in} = ET_{in} \; x \; TL_n \quad (10)$$

$$T_{in} = E_{in} \; x \; TC \; x \; TP \quad (11)$$

$$C_{in} = CD_{in} + CID_{in} \quad (12)$$

Decision variables:

$x_i$ = Solar rooftop PV systems scenario, where $i \in I$, $I = \{1, 2, 3 \ldots I\}$

Subject to:

$\sum_i x_i = 1, i \in I$ (13)
$C_i + CO_i \leq C_h$ (14)
$S_{PS} = (S_{PM} \times N_{PM}).x_i$ (15)
$S_{PS} = (\text{Maks } 80\% \times S_B).x_i$ (16)
$Q_{PS} = (N_{PM} \times Q_{PM}).x_i$ (17)
$x_i \in 0,1$ (18)

Parameters:

$n$ = solar rooftop PV system lifetime (n= 1,2,3…25)
$E_{in}$ = energy output of solar rooftop PV system in USD/kWp
$ET_{in}$ = energy output of solar rooftop PV system in kWh/kWp
$TL_n$ = electricity tariff of PLN in USD/kWh
$T_{in}$ = carbon tax that can be avoided by using solar rooftop PV system in USD/kWp
$TC$ = conversion factor of $CO_2$ emissions that can be reduced
$TP$ = carbon tax tariff in USD / $tCO_2eq$
$C_{in}$ = initial cost investment of solar rooftop PV system in USD/kWp
$CO_{in}$ = operational and maintenance cost of solar rooftop PV system in USD/kWp
$C_h$ = capital capability for initial cost investments in a solar rooftop PV system in USD
$CD_{in}$ = direct capital cost of solar rooftop PV system in IDR/kWp
$CID_{in}$ = indirect capital cost of solar rooftop PV system in USD/kWp
$N_{PM}$ = number of PV modules unit
$S_{PS}$ = total area of PV module on the roof in $m^2$
$S_{PM}$ = PV module area per unit in $m^2$
$S_B$ = total available roof area in $m^2$
$Q_{PM}$ = PV module power capacity per unit in Wp
$Q_{PS}$ = nominal capacity of solar rooftop PV system in MWp

The mathematical model is translated into the Solver Microfost Excel Office 365 add-on software by inserting objective functions, decision variables, and all constraints into the model. After entering all the values obtained from the results of the previous energy, economic and environmental analysis in the Bekasi case study (Tabel 3).

The results of running the optimization model for solar rooftop PV systems case study Bekasi show that the optimum or maximum benefit value of the solar rooftop PV systems in the Bekasi case study for 25 years was obtained from the use of scenario 4. This optimization resulted in the total benefit value of the solar rooftop PV systems of USD 1,416,428. This value is obtained by utilizing the maximum available roof area, which is 80% of the total available roof area. Utilization of 80% of the roof area by using scenario 4 can increase the total nominal capacity of solar rooftop PV systems to 12,986 MWp.

## 5. Discussion

### A. *Potential Energy Output Versus Solar Rooftop PV System Specifications of all Scenarios*

The results obtained from this comparison are that scenario 2 can produce the most electrical energy for 25 years of operation for both case studies. In total, scenario 2 has the potential to generate 195 GWh of electrical energy for the Bekasi case study (Figure 1) and 83 GWh for the Semarang case study (Figure 2). Although the nominal power and efficiency level of scenario 2 is lower than scenario 4, scenario 2 has the smallest performance degradation (Table 1) value compared to other scenarios, which is 0.25% per year.

### B. *Potential Energy output Versus PLN Electricity Consumption*

The results of the analysis show that scenario 2 is the scenario with the highest percentage of solar rooftop PV systems electricity output compared to the total electricity consumption of PLN in the two case studies for 25 years of operation. In total, scenario 2 can replace PLN's electricity consumption of 195 GWh or around 18.74% for the Bekasi case study (Figure 4). Meanwhile, for the Semarang case study, Scenario 2 can replace PLN's electricity consumption of 83 GWh or around 27.85% (Figure 5)

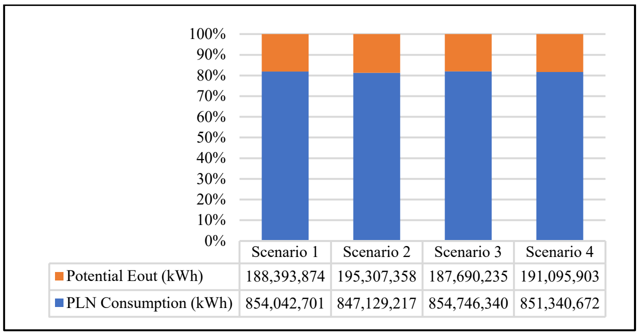


*Figure 4. Potential energy output solar PV system compared with PLN electricity consumption at Bekasi case study*

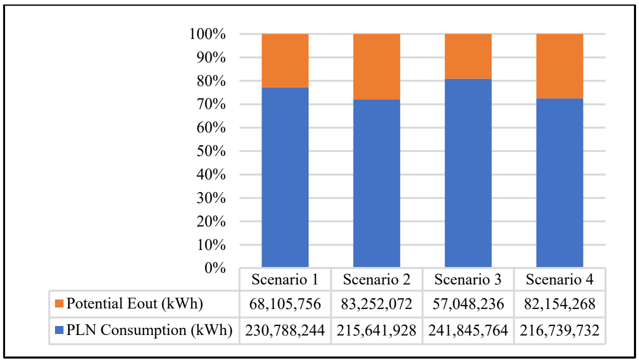


*Figure 5. Potential energy output solar PV system compared with PLN electricity consumption at Semarang case study*

### *C. Potential Energy output Versus Total Cost of Solar Rooftop PV System*

The results of this comparison show that the energy output (USD) has a higher value than the total costs incurred to install and operate the solar rooftop PV systems for 25 years of operation, except for scenario 3 in the Bekasi case study. Scenario 4 is the scenario with the largest amount of difference between energy output in USD and the total cost of the solar rooftop PV system, which is USD 1,910,663 or about 36% of the total cost of solar rooftop PV systems for the Bekasi case study (Figure 6). Meanwhile, for the Semarang case study, scenario 4 has the largest amount of difference, which is USD 1,150,768, or 58% of the total cost of solar rooftop PV systems (Figure 7).

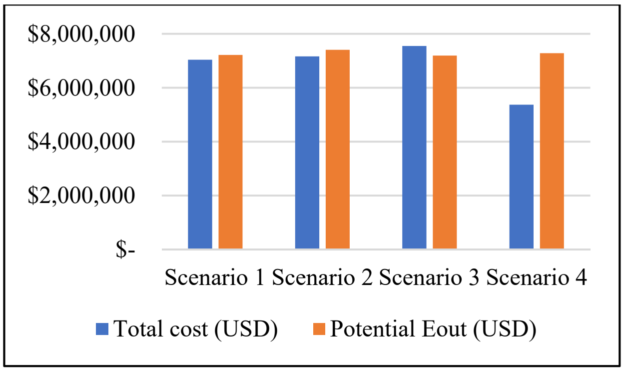


*Figure 6. Potential energy output compared with the total cost of the solar PV system at the Bekasi case study*

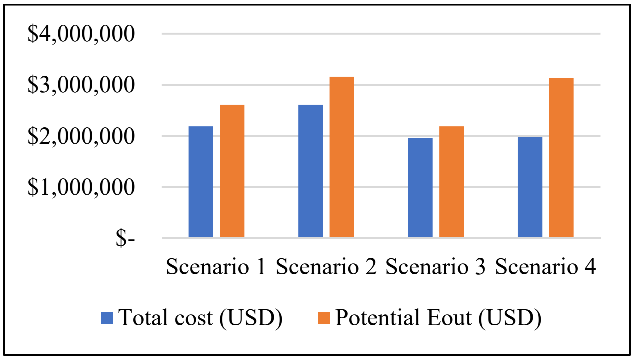


*Figure 7. Potential energy output compared with the total cost of the solar PV system at the Semarang case study*

### *D. LCOE solar rooftop PV system versus the PLN electricity tariff*

The results of the LCOE on the Bekasi and Semarang case studies which are in Table 2 are compared with the PLN electricity tariff for the industry that applies in Indonesia in 2021, which is USD 0.072/kWh. The comparison results show that only scenario 4 has an LCOE value below the PLN electricity tariff in 2021, which is USD 0.065/kWh. This indicates that the cost of generating electricity per kWh from solar rooftop PV systems from scenario 4 is cheaper than buying electricity from PLN. The same applies to the Semarang case study, where only scenario 4 has an LCOE value below the 2021 PLN electricity tariff, which is USD 0.056/kWh. Meanwhile, for other scenarios, it is still more expensive than PLN's electricity tariff.

### *E. Analysis of the Increase in PLN Electricity rates in July 2022*

The Indonesian government recently issued a new policy related to the increase in PLN electricity rates which will take effect from July 1, 2022. Whereas for household customers the tariff adjusted around 17.6% higher than the current tariff. If this increase also occurs in PLN customers in the industrial segment, this will have an impact on the comparison of the LCOE solar rooftop PV systems with PLN electricity rates for the industry in Indonesia in the two case studies in this study. For the Bekasi case study, with an increase in the PLN electricity tariff by 17.6% or to USD 0.085/kWh, the LCOE for scenario 4 will not change or is still below the PLN electricity rate. Meanwhile, for scenario 2, the increase in the PLN electricity tariff will make the LCOE the same as the PLN electricity tariff. Lastly, for scenarios 1 and 3, the increase in PLN's electricity tariff will still make the LCOE higher than the PLN electricity tariff. It is different from the Semarang case study, where the impact of the increase in PLN electricity rates will make the LCOE for all scenarios lower than the PLN electricity rates.

### *F. $CO_2$ Emissions that can be Reduced Versus the Total cost of Solar Rooftop PV System*

The amount of $CO_2$ emissions that can be reduced from the use of solar rooftop PV systems electricity can be converted into money (USD) by multiplying by the $CO_2$ price per tonne that applies to the carbon tax, which is USD 0.147 / $tCO_2eq$. The amount of $CO_2$ emissions that have been converted into money is then compared with the total cost of solar rooftop PV systems for each scenario.

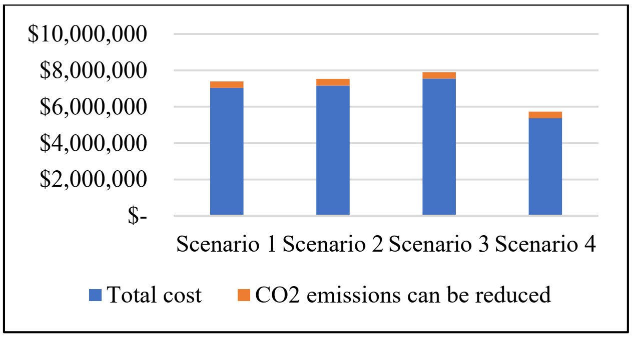


*Figure 8. $CO_2$ emissions that can be reduced compared with the total cost of the solar PV system in the Bekasi case study*

The results of the analysis show that in the Bekasi case study, scenario 2 can reduce $CO_2$ emissions the most compared to other scenarios for 25 years of operation, which is 174k $tCO_2eq$. However, if the amount of $CO_2$ is compared with the total cost used to build and operate a solar rooftop PV system for 25 years (Figure 8), then the highest percentage of value is obtained by scenario 4 which is 6.65% while scenario 2 is only 5.1%. This shows that scenario 4 can reduce the amount of $CO_2$ emissions more economically than other solar rooftop PV systems scenarios.

The comparison results in the Bekasi case study are not much different from the comparison results in the Semarang case study. Where scenario 2 is the scenario that can reduce $CO_2$ emissions the most compared to other scenarios for 25 operational years, which is as much as 74k $tCO_2eq$. And if the amount of $CO_2$ is compared with the total cost used to build and operate a solar rooftop PV system for 25 years (Figure 9), then the highest percentage of value is gained by scenario 4. Scenario 4 has a percentage value of 7.75% while scenario 2 is only 5.96%.

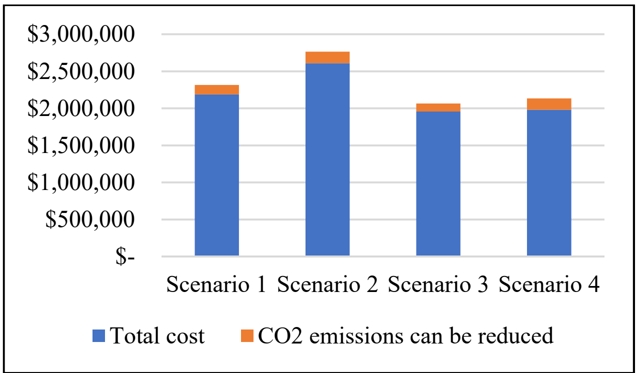


*Figure 9. $CO_2$ emissions that can be reduced compared with the total cost of the solar PV system in the Semarang case study*

### G. *Analysis of Benefit Value Optimizing Results of the Solar Rooftop PV System*

The optimization analysis of the benefits value of solar rooftop PV systems is carried out to see the impact of changes after optimization on the amount of energy output, the comparison of energy output with the total cost of solar rooftop PV systems, and the amount of $CO_2$ emissions that can be reduced. The optimization results of the previous benefit value in the Bekasi case study, show that the use of 80% of the total available roof area can increase the capacity of the solar rooftop PV system from 7,134 MWp to 12,986 MWp or around 82% by using scenario 4. Where the total roof area used if using scenario 4 in the previous condition is only 31,659 m2 or around 43.97%. The total benefit that can be obtained using scenario 4 on solar rooftop PV system Bekasi using 80% of the total available roof area is USD 1,416,428.

The first analysis of the optimization results is to compare the amount of energy output in scenario 4 before and after optimization for 25 years of operation. In total, scenario 4 in the Bekasi case study can produce a total electrical energy output of 347 GWh after optimization. This number increased by 156 GWh from the previous one which was only able to produce an electrical output of 191 GWh for 25 years of operation.

The second analysis is the comparison between the energy output of the solar rooftop PV system with the total electricity consumption of PLN in the Bekasi case study for 25 years of operation. In the conditions before optimization, the comparison of the energy output of electricity from scenario 4 was only 18.33% of the total electricity consumption of PLN. However, after optimization, the comparison of the energy output of solar rooftop PV systems increased to 33.37% of the total electricity consumption of PLN.

Finally, the analysis is the comparison between the amount of $CO_2$ that can be reduced both in units of amount ($tCO_2e$) and in the form of money (USD). Where the amount of $CO_2$ emissions that can be reduced by scenario 4 in the Bekasi case study for 25 operational years before the optimization is 170,266 $tCO_2eq$. This number increased after optimization, which increased to 309,910 $tCO_2eq$, or an increase of 82%. Meanwhile, if the amount of $CO_2$ is converted into money (USD), then the amount of $CO_2$ that can be reduced from the previous amount of USD 357,327 can be increased to USD 650,390.

## 6. Conclusions

The results of the study show that scenario 2 solar rooftop photovoltaic system can produce more electrical energy and $CO_2$ that can be reduced than the other scenarios in the two case studies. While scenario 4 solar rooftop photovoltaic system is a scenario with better economic value than the other scenarios in the two case studies. In addition, the results of optimizing the use of 80% of the roof area in the Bekasi 1 case study show that scenario 4 can provide the most optimum benefit value of Rp. 20,247,839,358 and can increase the amount of electrical energy and $CO_2$ that can be reduced by 82%. Finally, the optimization results of scenario 4 can increase the percentage of solar rooftop photovoltaic system electricity to the total electricity consumption of PLN to 33%. The use of scenario 4 solar rooftop photovoltaic system in as much as 80% of the available roof area can also reduce the use of PLN electricity (fossil energy) by 33% in the Bekasi 1 case study and 28% in the Semarang case study.

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