Techno-Economic Evaluation of Solar Rooftop Photovoltaic Systems at Factory Building in Indonesia

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Abstract

Indonesia is currently trying to transition from fossil fuel energy to renewable energy. From the six types of renewable energy identified for their potential, solar energy has the highest potential compared to other types of renewable energy, which is 207.8 GWp. One of the ways to utilize this incredible potential of solar energy is by installing solar PV systems on the roof of the building. This study aims to conduct a techno-economic evaluation of a solar PV system installed on the roof of a factory building through a case study of a multinational company in Indonesia. The evaluation result shows that the solar PV system has produced 7.4 GWh of electricity from January to December 2021, and the performance ratio is between 63.8% and 84.58%. The electricity produced is used as a backup power supply from the State Electricity Company in Indonesia. The economic evaluation shows that the solar PV systems have a positive net present value with 10.8 years of investment return. CO2 saved emission by using this clean energy is calculated at 168,253 ton CO_2 equivalent for 25 years of solar PV system lifetime.

Keywords
Renewable energy, Techno-economic evaluation, Solar PV system, Factory building.

1. Introduction
Indonesia has many potential alternative energy alternatives to support the transition from fossil energy to renewable energy. The immense potential of renewable energy in Indonesia is solar energy, 207.8 GWp or 47% of total potential renewable energy (Ministry of Energy and Mineral Resources of the Republic of Indonesia, 2019). However, the realization of the solar power plant is only 0.15 GWp or 0.07% of total potential renewable energy. The Indonesian government needs to drive more realization of renewable energy, especially solar energy, as their commitment to the Paris Agreement to reduce the carbon emission to solve the global climate change issue. The Indonesian government has released several policies to solve this problem. One of them is releasing Presidential Regulation number 22 in 2017, called National Energy General Plan (RUEN). The renewable energy use target in 2025 is 23% of total energy usage, and the rest is still using fossil energy. Moreover, it also stated that in 2050, the Indonesian government had set the target of renewable energy usage by 31% of the total energy used (Presidential Regulation, 2017). Regarding solar energy usage, the Presidential decree also contains the target realization of solar rooftop photovoltaic in Indonesia, which is 2.96 GWp of the solar rooftop in 2035 (IESR, 2021).

The government's policies and strategies encourage the installation of solar rooftop photovoltaic by the government, industry, and individuals. One of the policies is Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia No. 49 of 2018 concerning rooftop solar power generation systems by consumers of the State Electricity Company "PLN" (Ministry of Energy and Mineral Resources of the Republic of Indonesia, 2018). There is a reason why the Indonesian government is focusing on solar rooftop photovoltaic rather than other solar energy utilization, considering the development over the last two years is very significant. The installed capacity of rooftop solar power plants has almost doubled, growing from 16.66 MWp in 2019 to 30.38 MWp in 2020, mainly from the growth of the industrial segment (IESR, 2021). According to Fitriyani and Eko (2018), four factors underlie the potential implementation of solar rooftop photovoltaic in the industrial sector in Indonesia. First, load profile and industrial location, where the electrical load occurs more during the day than in the afternoon or evening, can be supplied by solar rooftop photovoltaic energy. The second is the readiness of infrastructure and experts. The condition of electricity infrastructure in industrial areas is usually reliable, stable and the power quality is good. The third is environmental and social impacts. The massive use of solar energy in industrial areas will reduce fuel oil usage, air pollution, and noise levels around the workplace. The objective of a sustainable industrial area environment will be achieved, and a positive image will develop for industry players. The last is potential savings. The installation of solar rooftop photovoltaic in the industrial sector will impact long-term financial benefits, given the tendency of PLN's electricity tariffs to continue to increase, while energy costs (IDR/kWh) from solar rooftop photovoltaic are getting cheaper.

This paper will discuss further the techno-economic evaluation of a solar rooftop photovoltaic system in a factory building in Indonesia. The evaluation was taken at one of the multinational companies in Indonesia, which has a factory building located in Bekasi, West Java province. The company has installed the grid-connected solar rooftop photovoltaic system in their factory since the beginning of 2021 with a nominal capacity of 7,1 MWp. The company was very concerned about the environmental issue, especially about CO_2 emission global. They aim to reduce the CO_2 emission by 30% in the next 10 years and net zero in 2040. In Indonesia, they start using this clean energy at their factory building in Bekasi in 2021 and will continue with other factories in the following years.

1.1 Objectives

This research aims to evaluate the techno-economic of the solar rooftop photovoltaic system in the industrial sector, which takes the case at one of the multinational companies in Indonesia. The evaluation is based on the actual performance data of the PV systems. This research topic is an interesting topic due to the significant development of solar rooftop photovoltaic in Indonesia, especially in the industrial sector, in the last three years. This research can give information to the industrial players in Indonesia about the feasibility of solar rooftop photovoltaic systems with current policy and regulations by the Indonesian government.

2. Literature Review

2.1 Solar Energy

Solar energy is the alternative energy resource that can be used as the best option to substitute fossil energy. Several reasons why solar energy has become the best renewable energy option (Kannan & Vakeesan, 2016). The first is because solar energy is the most plentiful renewable energy source. The second is because of the availability of solar energy that never ends. The third is because solar energy utilization does not have any harmful impact. Forth is that it can be used for any kind of sector, such as industrial, residential, and suburban areas. Indonesia has an advantage in utilizing solar energy sources that are its geographical position on the equator. With this position, Indonesia has enormous potential in utilizing solar energy as one of the alternative energy to replace fossil energy usage. Indonesia has the highest potential to receive solar radiation compared to temperate countries because the duration of sunlight in these countries is high in a year (Kannan & Vakeesan, 2016). The daily average Global Horizontal Irradiance (GHI) for Indonesia's western territory is lower than the eastern Indonesian territory (Veldhuis & Reinders, 2015). The GHI of western Indonesian territory is approximately 4.5 $kWh/m^2/day$ with a monthly variation of around 10%. The GHI of the eastern Indonesian territory is approximately 5.1 $kWh/m^2/day$, with a monthly variation of around 9%. The daily average solar irradiation intensity received for total Indonesia is in the range of 3.6 – 6 $kWh/m^2/day$. It is equivalent to the annual power output that can be generated by 1,170 – 1,530 kWh/kWp (The World Bank, 2017).

Research about solar energy potential in Indonesia commenced a long time ago, even before the energy policies were released in 2007. Several aspects of Indonesian solar energy research have been researched in the last 30 years (Madsuha et al., 2021). The solar resource and PV power potential are the strength of solar energy in Indonesia. At the same time, the weaknesses are small and isolated communities, high cost of grid connection, terrain constraints, and air pollution in urban areas. Besides that, Indonesia still has the opportunities to regarding solar energy, such as growing demand for electricity, international support programs, reduced cost of PV, and combination with other renewable energy. Meanwhile, the geographical risks and extreme events threaten solar energy development in Indonesia (The World Bank, 2017).

The use of solar energy can be divided into two categories. The first is the direct source of heat energy, and the second is used as the source of light to be converted directly into electricity (Singh, 2013). Solar energy applications are the source of heat energy such as heating for buildings, heat generation for industries, heating of water, cooking, and many other applications. On the other hand, photovoltaic is a process of producing electricity by using solar irradiance in light. This process can be divided into three kinds, stand-alone photovoltaic system, grid-connected photovoltaic system, and hybris photovoltaic system (Jager et al., 2014).

2.2 Solar rooftop PV system

Two ways are employed to generate the electrical power that humans use today. The dynamic electromagnetic generator is the earliest method for generating electrical power. Michael Faraday devised this technology in 1821, and it was first commercially produced in 1890. The generation of electrical power from solar cells is the second approach (Twidell & Weir, 2015).

The types of photovoltaics cells can be divided into three groups of cell generations. The first generation of cell-making materials consisted of silicon material processed into crystals with a high level of purity which was then called crystalline silicon. Crystalline silicon is divided into monocrystalline and polycrystalline silicon (Widharma, 2021). The second-generation cells use thin-film cell technology. This type is cheaper than the first generation cells because it uses less semiconductor material, although it has a limited efficiency of around 6-8%, known as TFPV (Thin Film Photovoltaic). The second-generation cell is usually applied for smaller and cheaper solar energy applications. Several types of second-generation cells that are often used are Copper Indium Gallium Diselenide (CIGS), Gallium Arsenide (GAAS), Amorphous Thin–Film Silicon, and Cadmium Telluride (CDTE) (Widharma, 2021). Third-generation cells can also be called hybrid cells. It is a combination of first and second-generation cells. The third-generation production costs are similar to the second-generation cells but have equal efficiency with the first-generation cells. Several types of third-generation solar cells are currently being developed are Dye-Sensitized Solar cells (DSSC) and Perovskite (Mohammad Bagher, 2015).

Solar photovoltaic systems consist of stand-alone systems, grid-connected, and hybrid (Jager et al., 2014). The difference between the stand-alone solar PV system and the grid-connected system is that the stand-alone system only uses the power generated from the PV system. At the same time, the grid-connected system uses the power from the PV system and the grid. Stand-alone and grid-connected can be combined with additional energy storage or battery components. The solar PV hybrid system combines solar PV systems with other sources of electricity generators, such as diesel generators or other renewable energy sources. Several components generally found in the solar photovoltaic system are photovoltaic module, inverter or DC-AC converter, energy storage or battery, cable, and mounting structure.

2.3 Techno-Economic Evaluation

Research on the techno-economic evaluation and analysis of solar rooftop photovoltaic systems has been carried out in many countries worldwide. The evaluation takes several buildings that installed the solar rooftop PV systems. Whether in schools or education buildings, commercial buildings (Miftahurrahman et al., 2019), factories or industries buildings, residential buildings, or public facilities. Renewable energy projects such as solar rooftop photovoltaic systems need regular evaluation because they use huge investments and need to make this project profitable, especially for a private company (Bilqist et al., 2018). The huge investment used in this renewable energy project needs to be tracked and monitored in the real-time and integrated bidding process to prevent corruption initiatives (Dachyar & Karenina, 2020).

A performance or energy analysis, economic analysis, and an environmental study are all part of the techno-economic evaluation. The literature analysis revealed that there is still a need for techno-economic evaluation of the PV system for industrial or factory buildings, especially in Indonesia (Madsuha et al., 2021).

2.3.1 Energy Evaluation

a) Solar potential assessment is an assessment that measures solar radiation in a certain location. Solar potential assessment is the main parameter that mainly affects the amount of energy generated by the solar PV system. It also affects the efficiency of the PV system. The amount of energy received per unit area and time on Earth is called solar radiation. General sources of solar irradiation data for a particular location can be obtained from 3 sources meteorological stations, experimental data, and online databases such as Meteonorm (Paudel et al., 2021). Several country locations that used their solar potential assessment for the feasibility assessment of solar rooftop photovoltaic systems in previous studies include India (Saxena et al., 2021), Nepal (Paudel et al., 2021), Hong Kong (Shi et al., 2021), Bangladesh (Datta et al., 2020), Turkey (Duman & Güler, 2020), Egypt (Ibrahim et al., 2018), Maldives (Ali et al., 2018), and Brazil (Miranda et al., 2015).

b) The performance ratio is the ratio value between final yield (Y_f) and reference yield (Y_r). It represents the actual energy generated by the solar PV system to the expected energy from its nameplate rating. According to the International Electro-Technical Commission (IEC) 61724, the Performance Ratio can be calculated (Nugroho & Sudiarto, 2021) as Equation (1) below:

$$PR = Y_f / Y_r \quad (1)$$

Where:
PR = performance ratio of the solar roofotp PV system
Y_f = the final yield of the solar rooftop PV system
Y_r = reference yield

Final yield results of net AC energy generated by the accumulation of photovoltaic systems divided by the installed PV array's peak power at STC over a certain period. Final yield can be expressed in daily, monthly, and yearly periods as Equation (2) below.

$$Y_f = E_{out} / P_N \quad (2)$$

Where:
Y_f = the final yield of the solar rooftop PV system
E_{out} = the AC energy output of the solar rooftop PV system (kWh)
P_N = Nominal power or the peak power of the solar rooftop PV array at STC (kW_p)

The *reference yield* (Y_r) is the value comparison between total in-plane irradiance with the PV's reference irradiance. The PV reference irradiance itself is measured at Standard Test Condition, which the value is 1000 W/m^2. The *reference yield* formula can be expressed as Equation (3) below:

$$Y_r = \text{Total in-plane irradiance} / \text{PV reference irradiance} \quad (3)$$

Where:
Y_R = reference yield
Total in-plane irradiance expressed in kWh/m^2
PV reference irradiance expressed in kW/m^2

2.3.2 Economic Evaluation

a) Net Present Value (NPV) can be interpreted as the difference between the net cash flows in and the net cash flows out for a certain period considering the prevailing bank interest rates. Net Present Value (NPV) is one of the indicators used to assess the construction of solar rooftop PV systems in several previous studies. Where the NPV value of a project is said to be profitable if it has an NPV value more than 0, which is calculated by the following formula as Equation (4) below (Haegermark et al., 2017):

$$NPV = \sum_{n=0}^{N} (C_n/(1+r)^n) \quad (4)$$

Where:
C = cash flow (positive or negative)
n = year of cash flow
N = total number of years of cash flows
r = discount rate

b) Levelized Cost Of Energy (LCOE) is the cost incurred to generate electricity per kWh from a power generation facility. LCOE is used to compare the cost-effectiveness of various energy/power generation technologies with different technologies. In simple terms, LCOE can be formulated as Equation (5) below (Branker et al., 2011):

$$LCOE = \frac{\left[\left(\sum_{t=0}^{N} Ct\right)/(1+r)\hat{}t\right]}{\left[\left(\sum_{t=0}^{N} Er\right)/(1+r)\hat{}t\right]} \quad (5)$$

Where:

C_t	= the net cost of the project for a period time of t in years
E_r	= the solar energy produced by the solar PV system in kWh
N	= the life of the project in years
r	= discount rate
t	= the lifetime of the project

c) Pay Back Period (PBP) is simply the length of time the return on investment capital spent to implement a project. PBP has measured in time (years) units and is based on annual energy savings obtained from a project. The smaller the value of a PBP means that the project carried out has a decent economic value. On the other hand, if the value of the PBP is significant, then the project can be said to be unfeasible. Mathematically, the PBP calculation can be written as follows as Equation (6) below (Paudel et al., 2021):

$$\text{Pay Back Period (PBP)} = \frac{Initial\ investment}{Revenue\ generated\ per\ year} \tag{6}$$

d) Benefit-Cost Ratio (BCR) can be interpreted as a comparison value between the benefits generated by a project or net returns compared to the costs incurred for working on the project itself or gross expenditures. In the economic feasibility analysis of a project, BCR is usually used as a complement or addition when other economic feasibility analysis methods have been carried out. BCR is used as a validation step for the other economic evaluation that has been done. The calculation of the BCR value mathematically can be written as follows as Equation (7) below (Rafique & Bahaidarah, 2019)

$$\text{Benefit Cost Ratio (BCR)} = \frac{Net\ Returns}{Gross\ Expenditures} \tag{7}$$

e) The Internal Rate of Return (IRR) is the interest rate that can produce the same value between costs or investments with revenues. Internal rate of return can also be defined as an interest rate equal to the NPV value = 0. The IRR calculation is based on the calculation of present and annual values. The calculation of the IRR value can be done using the following formula as Equation (8) below (Duman & Güler, 2020):

$$\sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0 = 0 \tag{8}$$

Where:

C_t	= the net cost flow in period t (years)
C_0	= the initial investement cost
IRR	= the internal rate of return
T	= the lifetime of the project

2.3.3 Environmental Evaluation

Environmental evaluation calculates the amount of CO_2 emissions that can be saved by using the energy produced by the PV system. Currently, the energy used for the multinational company's factory comes from the electricity grid, which is produced from fossil energy. Calculation of the amount of CO_2 that can be saved through the use of solar energy or PV systems can be done using the following calculation formula as Equation (9) below (Tantisattayakul & Kanchanapiya, 2017):

$$ER_t = Eg_t \times EF_{Grid} \tag{9}$$

Where:

ER_t	= CO_2 emission saved in year t (tCO_2e/yr)
Eg_t	= Total of electricity generated from solar rooftop PV systems in year t (MWh/yr)
EF_{Grid}	= Emission factor for grid connected power generation (tCO_2e/MWh)

3. Methods

Several steps are taken to achieve the study's research objectives. A literature study was conducted first to better understand the topic and determine the research objective. After getting a clear picture of the topic of this research, a set of data regarding the solar rooftop photovoltaic evaluation was requested from the official member of the case study was taken. Data requested to the case study was taken are divided into two types: technical and economic data. The technical data consists of the technical building data, solar photovoltaic system data, irradiance data, energy yield, and performance ratio of solar rooftop photovoltaic system installed.

Meanwhile, the economic data contain the direct investment cost, indirect investment cost, operational; and maintenance cost for the solar rooftop photovoltaic system. After gathering the data, a 3E analysis (energy, economy, and environmental) method was carried out to evaluate the solar rooftop photovoltaic system. The energy evaluation is carried out using IEC 61724 regarding the standard of performance evaluation of solar PV systems. In comparison, the economic evaluation is carried out using economic engineering analysis.

4. Data Collection

Following its objectives, the study was conducted to evaluate the techno-economic performance of a solar rooftop photovoltaic system installed on a case study at one of the multinational companies in Indonesia. The evaluation was conducted through the 3E analysis method (Saxena et al., 2021). The data was collected by requesting the technical and economic data needed from the company. The technical data includes the data of solar photovoltaic technology profiles that have been installed and technical building data. The economic data consist of direct capital cost, indirect capital cost, and operation and maintenance cost for the lifetime of the solar photovoltaic system (Hay, 2016).

Period data requested to the company was taken from January until December 2021 for technical data (See Table 1) such as irradiance data, final yield, performance ratio. The solar rooftop photovoltaic was running in full capacity started on March 2021, while in January until February was running by half of its capacity.

Table 1. Solar PV design

Parameter	Value	
Location	Bekasi, West Java Province	
Roof area	72,000	m^2
Nominal capacity	7,134	kWp
The lifetime of solar PV	25	years
PV type	Mono-Si	
PV Wattage	395	Wp
PV efficiency	19.1	%
Rated Voltage (Vmpp)	43.2	V
Rated Current (Impp)	9.14	A
Open-Circuit Voltage (Voc)	52.5	V
Short-Circuit Current (Isc)	9.72	A
Inverter efficiency	98	%
Mounting type	Fixed mounting	

5. Results and Discussion

5.1 Energy Evaluation

The result of energy analysis was gathered directly from data online monitoring facility system of solar rooftop photovoltaic at one of the multinational companies in West Java province in Indonesia where the case study was taken. The period time of the data energy analysis was from January to December 2021. Figure 1 shows that the solar potential assessment of solar rooftop photovoltaic system in a year is 1,553 kWh/m^2 or 4.25 kWh/m^2/day. This number is aligned with the number from The World Bank that Indonesia has the daily average solar irradiation intensity in the range of 3.6 – 6 kWh/m^2/day (The World Bank, 2017). The peak solar irradiation value was 154,147.79 Wh/m^2 for September, while the lowest irradiation value was 80,221.90 Wh/m^2 for February. The solar irradiation varies every month, mainly depending on the season. Figure 2 shows that irradiance in January and February is lower than in other months due to the monsoon. From July until September, the irradiance was higher than another month due to the summer season in Wast Java province.

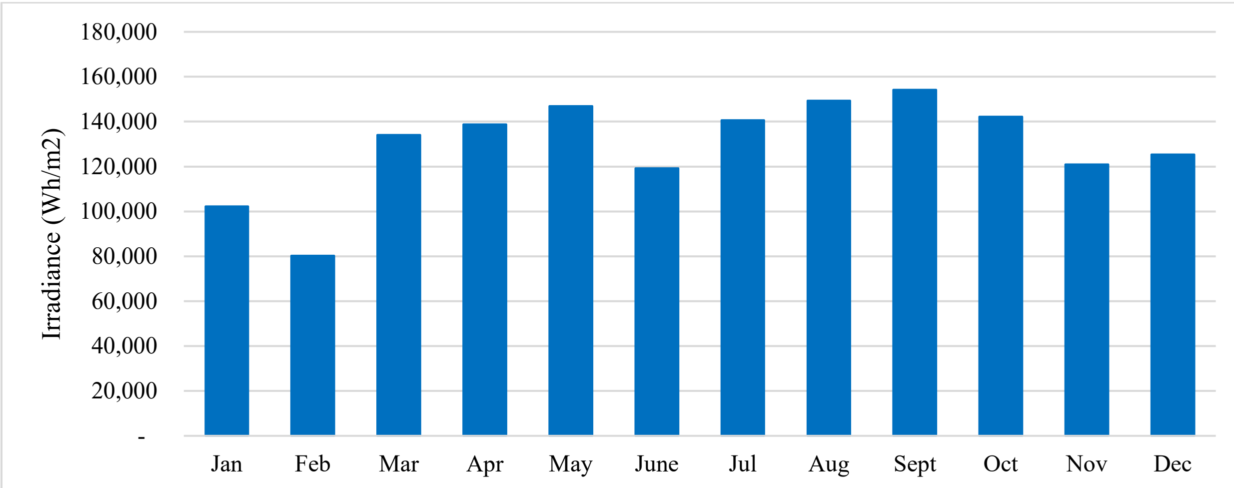

Figure 1. The monthly irradiance of solar rooftop photovoltaic system at one of the multinational companies in Indonesia in 2021

The monthly average energy yield from the solar rooftop photovoltaic system (Figure 2) was around 0.6 GWh. The lowest energy yield from this photovoltaic system was from January until February, due to the capacity installed at that time still half of its capacity. The total capacity of the solar rooftop photovoltaic system was installed in March and fully running in April. The energy output of the solar rooftop PV system was quite linear, with the solar irradiance received along the time in 2021. It is similar to the final yield analysis result, where the value of the final yield was linear with the solar irradiation received. Compared to The World Bank data of final yield solar rooftop photovoltaic system, the annual final yield value of 1,158 kWh/kWp was a little bit lower than the average Indonesian territory of 1,170 – 1,530 kWh/kWp (The World Bank, 2017). It is mainly due to the capacity of the solar rooftop PV system was not fully running from January until February.

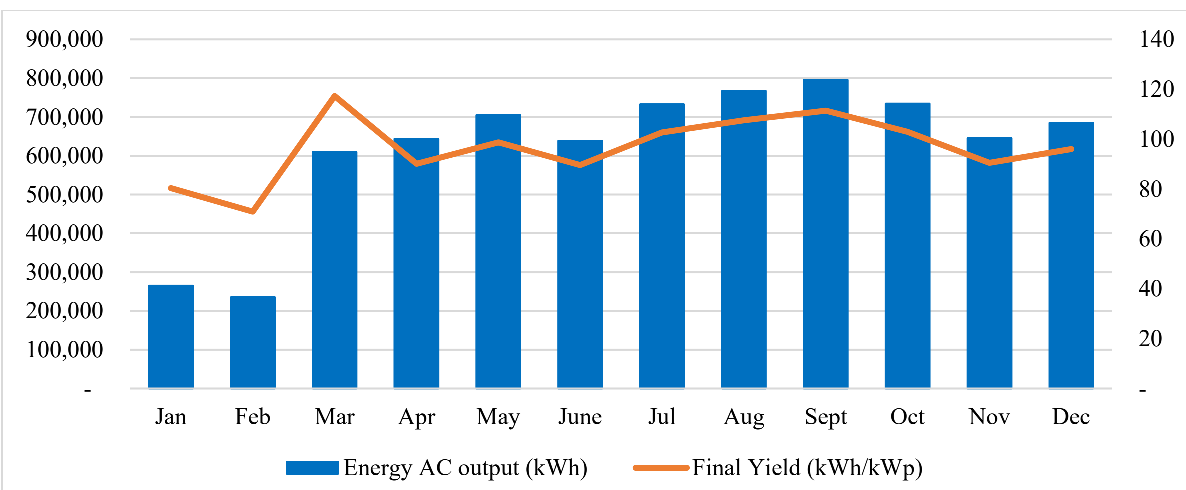

Figure 2. The monthly energy output of solar photovoltaic systems at one of the multinational companies in Indonesia in 2021

The performance ratio (PR) analysis result (Figure 3) shows that the monthly performance ratio ranges between 63.84% - 84.58%, with the annual PR at 73.02%. The performance losses consist of collective loss and system loss (Paudel et al., 2021). Collection loss is the performance loss caused by the PV array, while system loss is the performance loss caused by the system, such as inverter loss, wire loss, and other losses. The lowest performance ratio in the PV system was in April and May 2021, caused by the integration of the solar PV system to the grid. Compared to the performance ratio of the PV system at different locations in the world (Srivastava et al., 2020), the PR of the solar PV system is categorized in a good performance ratio level.

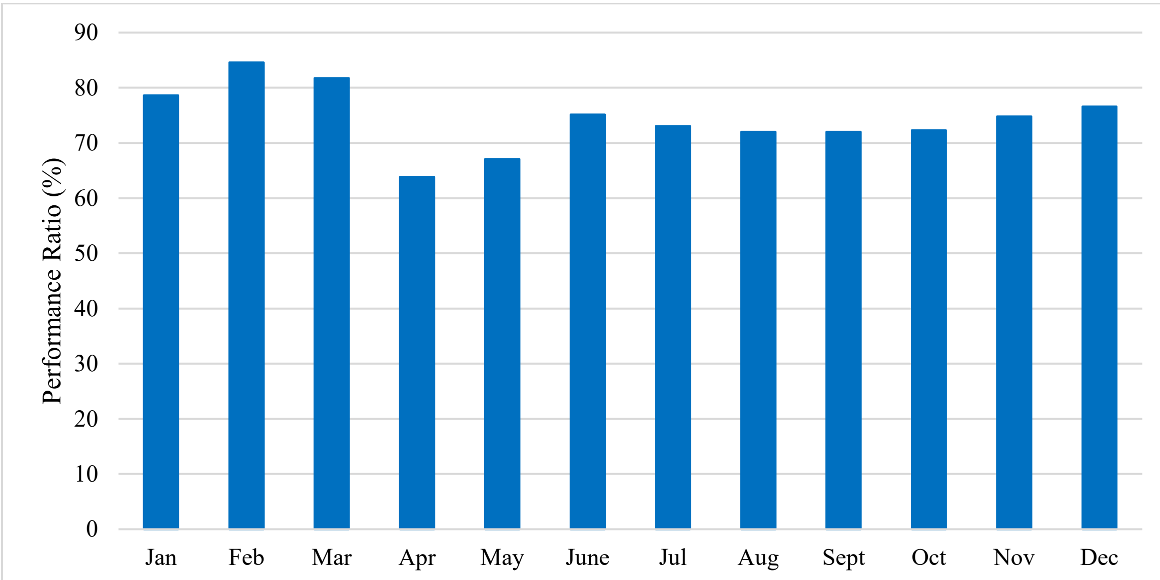

Figure 3. The performance ratio of solar photovoltaic systems at one of the multinational companies in Indonesia in 2021

5.2 Economic Evaluation

The economic evaluation of the solar rooftop PV system at one of the multinational companies in Indonesia uses several parameters and assumptions of the PV project. Table 2 shows the exact number of the parameters and assumptions used in the PV project.

Tabel 2. Parameter and assumptions of economic analysis

Parameter	Value
Investment	86 billion Rupiah
Operation and Maintenance cost	1.86% of initial investement per year
Project lifetime	25 years
Degradation of PV module performance	0.6% per year
Discount rate	8%

From the economic data analysis, solar rooftop PV systems at one of the multinational companies in Indonesia have an excellent financial parameter. The details can be seen below:

a) The Net Present Value analysis result shows that this solar rooftop PV system has NPV positive or more than 0. The positive NPV means that the solar rooftop PV system investment is projected to be profitable.
b) The Levelized Cost of Energy from the solar rooftop PV system is 1,914.36 IDR/kWh or 0.13 USD/kWh. Compare the LCOE of this solar PV system with the current industrial electricity tariff (0.07 USD/kWh), the solar PV system is not cost-effective.
c) Payback period, the result analysis shows the investment in the solar rooftop PV system will return in 10.8 years.
d) The benefit-cost ratio of the solar rooftop PV system is 1.02, and the internal rate of return of the solar rooftop PV system is 8.46%

5.3 Environment Evaluation

CO_2 saved emission was analyzed through the lifetime of solar rooftop photovoltaic design based on the specification of PV module (25 years). From the data analysis, the total CO_2 saved emission by the installation of solar rooftop photovoltaic system in factory building is calculated at 6,730 ton CO_2 eq per year on average or 168,253 ton CO_2 eq in the total lifetime of the solar PV system . Figure 4 shows that the CO_2 saved emission number is accumulatively increase by the time of solar rooftop photovoltaic system operates. It is aligned with the commitment of PT. XYZ to reduce the CO_2 emission in their operational activities and shift to clean energy usage.

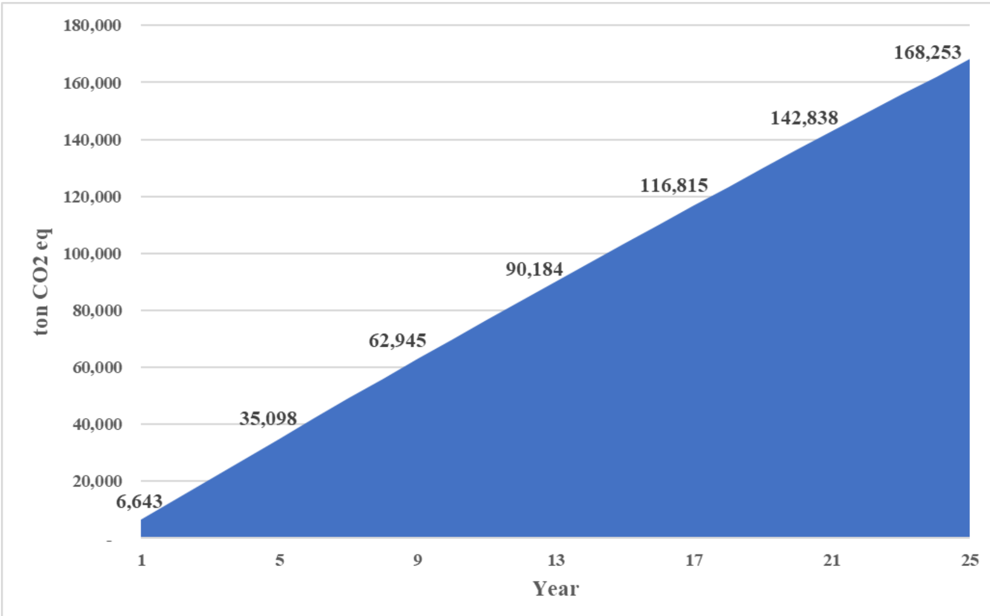

Figure 4. Accumulative CO_2 saved emission by solar rooftop PV system in 25 years lifetime

6. Conclusion

Based on the techno-economic evaluation conducted on solar rooftop photovoltaic systems at one of the multinational companies in Indonesia, it can be concluded that this solar PV system is feasible. The solar rooftop photovoltaic system has a good performance ratio which is ranged between 63.84% to 94.58%, with an annual average performance ratio of 73.02%. However, the annual energy yield of these solar PV systems has a little bit lower than the average Indonesian territory, which is 1,158 kWh/kWp. The economic analysis result shows that the solar PV system has a good financial parameter shown by positive NPV value, IRR value is 8.46% higher than the discounted rate used as an assumption, 10.8 years of payback period, and the benefit-cost ratio is more than 1. Meanwhile, the LCOE of the solar PV system is 1,914.36 IDR/kWh or 0.13 USD/kWh. It is still higher compared to the industrial electricity tariff from PLN. Total CO_2 saved emission by using clean energy from the solar rooftop photovoltaic system is estimated at 168,253 ton CO_2 eq for 25 years of solar PV systems lifetime. This number of CO_2-saved emissions contributes to the Indonesian government's target of the energy transition and also to the commitment of PT. XYZ of using clean energy in their operational activities.

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