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RESEARCH ARTICLE

Analysis of performance and economic value of thin film and monocrystalline photovoltaic systems in the tropical area of Jakarta

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Abstract

Evaluation of PV performance is important as a development in supporting the government's program to increase the renewable energy mix to reach 23% in 2025. This study aims to analyze the performance of thin film vs monocrystalline PV which has been operating in tropical areas in Jakarta. Then thin film and monocrystalline PV were simulated using PVsyst. Evaluation is carried out through a performance ratio analysis approach and the value of the degradation rate. The performance of thin film PV was 5% close to the simulation result but not for the monocrystalline silicon. The degradation rates for thin-film and mono-si were 0.93% and 2.07%, respectively. The degradation rates of PV are comparable to other studies that have been conducted in other countries with similar climates. Such a degradation rate value reduces the economic value of PV where the Levelized Cost of Energy (LCOE) value obtained decreases for thin films by 25% while for monocrystalline would change by 77%.

Keywords: Evaluation, Techno-economic, Degradation rate, PV, thin film, monocrystalline

1. Introduction

The need to reduce greenhouse gas emissions provides opportunities for the development of renewable energy as the main energy. Indonesia, which is an archipelagic country traversed by the equator, has very abundant potential for renewable energy, it's just that the potential that has just been utilized is still very little. Reported by IRENA, Indonesia's total renewable energy potential reaches 3,692 gigawatts (GW), but its utilization is only 0.3% of the existing potential. This potential consists of solar energy, wind, water, biomass, geothermal, and sea water. Indonesia does have a renewable energy mix target of 23% in 2025. However, in reality it has only been realized at 12.2% per 2023. This is a tough task for the government. Major efforts are needed in the form of careful planning, infrastructure capacity building, and large amounts of investment or funding.

For the DKI Jakarta area, the local government has undertaken efforts to boost the usage of renewable energy, one of which is through installing PV. Government buildings have installed PV as a source of electrical energy during the day, for example, the Public Health Center building, places of worship, offices and schools with various types of PV such as thin film and monocrystalline. This is in accordance with the local government's objective to cut greenhouse gas emissions by 30–50% in 2030 (Regional Action Plan 2017-2022). One of them is the installation of PV SMKN 2 Jakarta and the LAN Jakarta Building.

Research regarding design and performance evaluation has been conducted in some countries. Research [1] has analyzed that the mono-si in Senegal in which the degradation rate would be between 0.3%–3%/year. The 380 kW with a thin layer were installed in Malawi with the performance ratio of 79.5% [2]. The grid-connected PV park is installed in Bulgaria with the performance ratio varies from 52% to 83% with the average of 70.44% [ref3]. The PV rooftop designed to be mounted in rooftop in Yemen, has the total power loss up to 30% which result the performance ratio to be 65.1% [3]. The various types of PV has been compared with the subtropical climate by their performance ratio in which HIT technology got the best option [4]. The PV system with a capacity of 3 kWp had been simulated with PVsyst that conclude the losses in the PV system coul be inevitable [5]. In europe,

However, the studies under experimental settings of PV systems to examine their performance and determine their potential remain the most realistic because they are based on real data from existing and installed PV systems [6]. In the context of Indonesia and notably Jakarta, there is still limited information available regarding the practicality of rooftop PV systems. There have been no studies on rooftop PV performance analysis and energy production evaluation of PV systems functioning under real conditions in this location. For the PV development, research on the evaluation of PV installations plays a vital role as scientific evidence of the benefits of employing PV and as a subsequent development so that the building of PV is more efficient and lucrative for electricity customers.

From the reason previously mentioned, the performance in technical and economic aspect of the PV system would be conducted in this paper. The results of measurement would be compared with the simulation results using the PVsyst software. The degradation of the photovoltaic would be analyzed by the trend of energy yield for a certain time. The effect of the photovoltaic degradation for the economic value in the long term would be investigated (section 3). Finally, the conclusion and the future works are described in section 4.

2. Material and Techno-Economic Analysis Method

The two types of PV are designed to be installed in different areas in Jakarta. Zone 1 is located in Gambir with 6.17^o latitude dan 106.83o longitude. It was designed to be installed with the CIGS thin film. The second zone is in Pejompongan with 6.2^o

latitude dan 106.80o longitude with tilt angle of 10o that installed the monocrystalline silicon type of PV. The specifications of the PV and Inverter are shown in table 1 as follows.

Table 1. Photovoltaic Specification

	Zone 1	Zone 2
PV Type	CIGS Thin film	Monocrystalline silicon
Number of modules	120	336
Inverter Type	SMA Solar Inverter	SMA Solar Inverter
Number of Inverter	1	4

This study aims to investigate the performance of CIGS and monocrystalline thin film PV based on the simulation, the decline in PV performance after the simulation conducted, and the impact of changes in economic value due to the decreased of PV performance. In this study, the performance analysis between the CIGS thin film PV and monocrystalline silicon has been performed. Both of which have been operated for 16 months. The research flowchart is shown in Figure 1 regarding the step of the research.

The flowchart can be seen in Fig 1. In developing a system, the correct method is needed to produce the best results. The research stages started from a study of the research literature on PV performance evaluation that had been carried out in various nations, then took primary data on the PV output, which then simulated the data in the PVsyst software to serve as comparison analysis data. After the simulation, it is continued with a comparative analysis of PV performance between the actual situation at the PV location and the simulation results from PVsyst. Due to the differences in the capacity of the photovoltaic, the performance ratio would be deployed for the analysis to make it equal among them. The analysis of the degradation rate would be conducted by calculating the gradient performance ratio trend in 16 months operation of both photovoltaics. By the degradation rate, an increase in the Levelized Cost of Energy (LCOE) can be analyzed.

2.1 Reference Yield

The reference yield is the difference between the amount of reference radiation G0 (1 kW/m^2) and the total amount of solar radiation Ht (kWh/m^2) that the surface of the solar PV panel has received. The latter indicates how many hours correspond to the reference irradiance, and Yr stands for the solar resource. The formula of reference yield could be expressed as follows.

$$Y_r = \frac{Ht(kWh)}{G0(kW)} \tag{1}$$

2.2 PV system final yield

The final yield is calculated by dividing the total energy generated by the PV (EAC (kWh)) over to the nominal phptovoltaic installed power. This statistic, which is

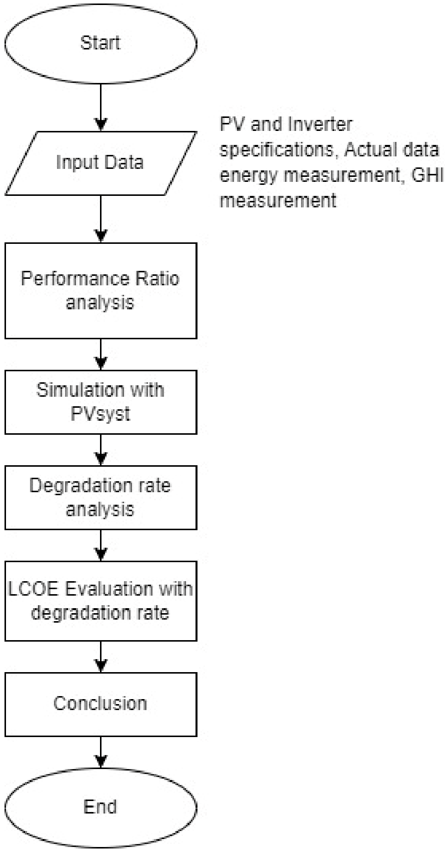

Figure 1. Flowchart of the research

presented as follows, indicates how many hours the PV array should run at full power.

$$Y_r = \frac{EAC(kWh)}{P0(kW)} \tag{2}$$

2.3 Performance Ratio

The PR performance report illustrates the overall impact of losses on a PV system's ability to produce electricity. PR values show how close a PV system comes to achieving its ideal performance under practical circumstances. PR is a dimensionless quantity that is calculated by subtracting the reference yield from the final yield.

$$PR = \frac{Yf}{Yr} \tag{3}$$

2.4 Degradation rate

The degradation rate is the rate at which the performance of an equipment decreases each year. Degradation rate can occur in PV along with age of use and external factors. Such external factors can result in one or more degradation problems such as corrosion, light-induced degradation (LID), cell breakage and cracking, discoloration, and delamination. In addition, degradation at the PV module level can occur affecting different components such as glass, interconnections between cells, encapsulation materials which are generally made of Ethylene Vinyl Acetate (EVA), diodes, Anti-Reflective coatings, protective polymer films, and glues used. to ensure adhesion between the different module constituents.

1. Least Square / linear regression. The linear regression method is a data analysis technique used to predict unknown data values using known and related data values. They then calculate the unknown future cost by halving the known future revenue. Metode Regresi linear would be expressed in the following equation.

$$Y = \alpha X + \beta + e \tag{4}$$

   where α is the slope of the trend, β is the intercept and e is denoted the error (observation deviation from the linear relationship). The LR technique tries to fit the above equation by minimizing the sum of squared residuals, using the ordinary least squares method.
2. Classical Seasonal Decomposition. CSD is a widely used as a method that decomposes time series objects by moving the average into seasonal, trending, and residual components. There are two basic decomposition models: additive (which is useful when seasonal variation is relatively constant over time) and multiplicative (which is useful when seasonal variation increases over time). To calculate the trend of the component, a 12-month centered moving average is applied to the time series. For a 2×k moving average, where k is the seasonal period (k=12 because of the number of months in the year), the centered moving average at time t is found as:

$$T_t = \frac{1}{2}\left(\frac{1}{k}\sum_{i=t-m}^{t+m-1} Y_i + \frac{1}{k}\sum_{i=t-m+1}^{t+m} Y_i\right) \tag{5}$$

   where Y is the original time series, Tt is the trend at time $t(t > m)$, and m is defined as half the width of the moving average, $m = k/2$. The moving average smoothing effect shapes the trend of each time series, which, given in the equation above, is half the seasonal period shorter at each end. Next, LR is applied to the trend component to calculate the value of the annual degradation rate.

$$Rd = \frac{a * 12}{b} * 100 \tag{6}$$

   where a is a slope, b is an intercept of the monthly performance function of times.

2.5 Leveleized cost of energy with Degradation rate.

LCOE calculations with degradation rates are carried out to find the changes of economic value after the PLTS has been operating for a certain time. These results are then compared with the calculation of LCOE during planning. The degradation rate would be incorporated for the LCOE calculation by the following equation.

$$LCOE = \sum_{t-1}^{n} \frac{\frac{I_t + M_t}{(1+i)^t}}{\frac{Et(1-d)^t}{(1+i)^t}} \tag{7}$$

While It denotes the initial investment (*V*). Mt shows the operation and maintenance costs (*V*) during the year *t* and *r* would be the discount rate (6%). *Et* is the energy produced by the photovoltaic during the first year (kWh) while it taking into account the actual measurement of energy yield and d is the degradation rate (%/year) that has been calculated. The symbol n is the lifetime of the project.

3. Results and Discussion

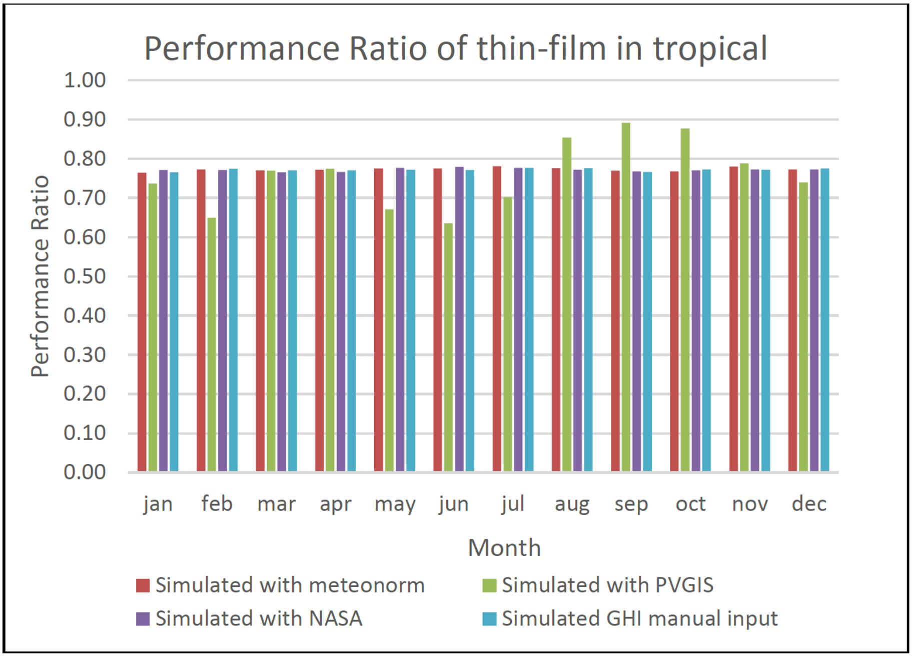

Figure 2. Performance Ratio of Thin Film PV in Simulation

Fig 1 performs the performance ratio of Thin Film PV in Simulation Data processing of the performance ratio of CIGS thin film regarding the results of energy measurements at CIGS thin film PV and simulation with PVsyst. After a year of operation, the performance ratio of the PV is 0.78. In the simulation with the meteonorm it has an average of 0.77 where the highest and lowest values are 0.78 and 0.66 respectively. In the simulation with PVGIS, the average of the simulation results is 0.76 with the maximum and minimum values respectively 0.89 and 0.64. At NASA, the average obtained is 0.77 with the maximum and minimum values with 0.78 and 0.77 respectively. For GHI manual input the results a value of 0.77 with a maximum value and a minimum value of 0.78 and 0.77 respectively. The deviation between the actual and the simulation is accounted for under 5%.

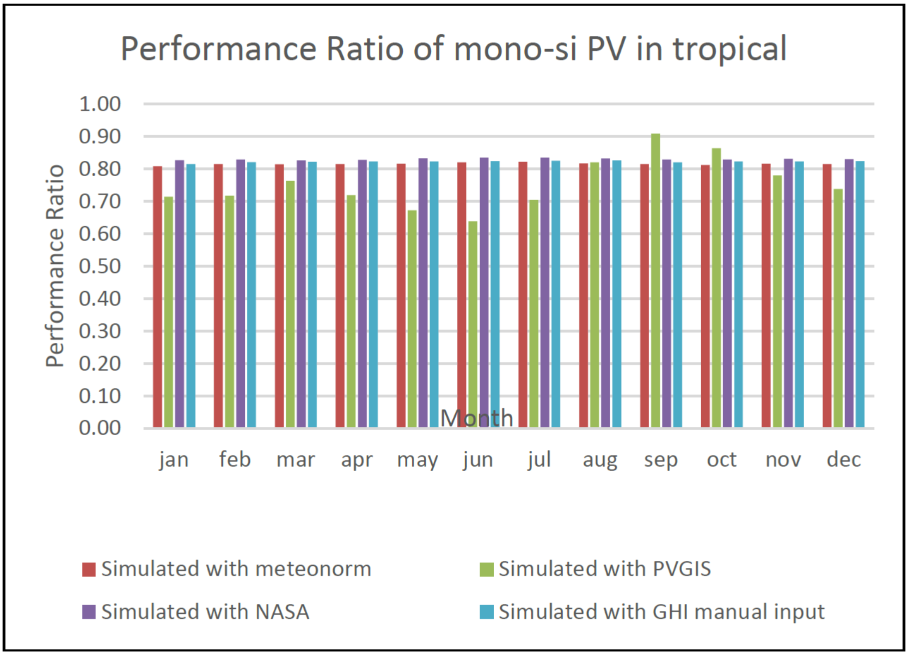

Figure 3. Performance Ratio of Thin Film PV in Simulation

Fig 2 Depicts performance ratio of monocrystalline silicon PV in Simulation Data processing of the performance ratio of monocrystalline silicon regarding the obtained results of energy measurements at mono-si PV and simulation with PVsyst. After a year of operation, the performance ratio of the PV is 0.65. In the simulation with the meteonorm it has an average of 0.82 where the highest and lowest values are 0.82 and 0.81 respectively. In the simulation with PVGIS, the average simulation result is 0.75 with the maximum and minimum values respectively being 0.91 and 0.64. At NASA, the average obtained is 0.83 with the maximum and minimum values respectively being 0.84 and 0.83. For GHI manual input it results an average of 0.82 with a maximum value and a minimum value of 0.83 and 0.82 respectively. There appears to be a significant difference between the actual measurement results and the simulation results (above 10%).

The warranty value corresponds to an annual degradation rate of 0.88%. A PV will have a performance below 80% in the 25th year if the deterioration rate is more than 0.88 percent per year. when the PV is 10 years but will be lower than 80% by the time it is 25 years old. This demonstrates the thin film solar energy has an excellent level of resistance in the tropics. Losses are more frequently brought on by outside factors that can be avoided with proper maintenance, like dirt or shade. The calculation of degradation rate is shown in table 2. Two metohds were used to find the degradation rate, LR and CSD.

Table 2. The calculate of degradation rate

	SMKN 2 JKT	Gedung LAN JKT
Least Square	1,1%/year	2,2%/year
Classical Seasonal Decomposition	0,76%/year	1,93%/year
Average	0,93%/year	2,07%/year

PV would still perform well at age 10 with a degradation rate of -0.93%/year the performance would be above 90%; yet, at age 25 with a performance slightly below 80% (below the warranty value), PV is still able to provide energy. Regular maintenance is therefore necessary to ensure that the PV continues to function in accordance with the manufacturer's warranty value. Regular maintenance is necessary due to tropical conditions that impact the state of the PV because oxidation, which is caused by high air temperature, humidity, and sunlight intensity, causes the color of the PV panel to change to brown. The trend of the degradation rate is shown in figure 4 CIGS thin film and figure 5 for monocrystalline silicon.

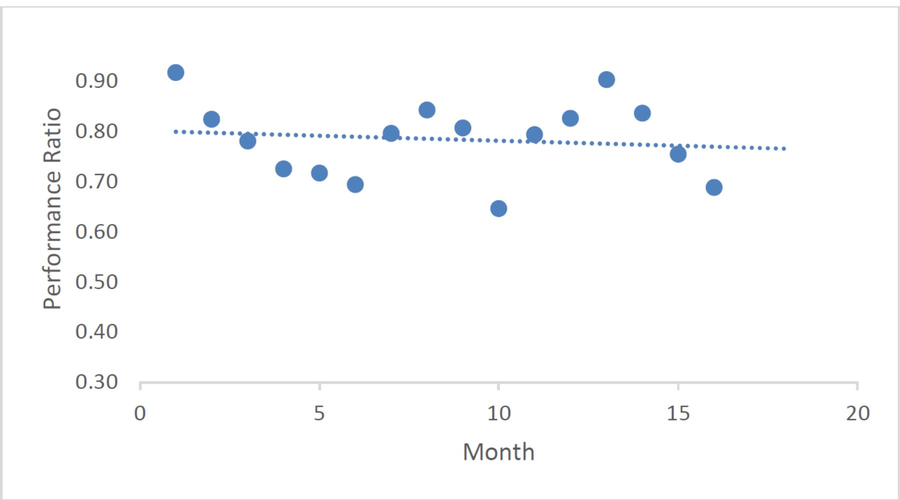

Figure 4. Monthly performance ratio of CIGS thin film PV.

Figure 4 shows the monthly performance ratio of the CIGS thin film PV after being operated in 16 months. Their performance ratio varied in the range of around 70%–90%. The performance of this PV denotes the downtrend that means the PV has degraded over time. Linear regression was used to find the the degradation rate which results in 1.1%/year while by the CSD method obtained 0.76%/year for the degradation rate. The CSD got the lower value for the calculation with the average of both are 0,93%/year.

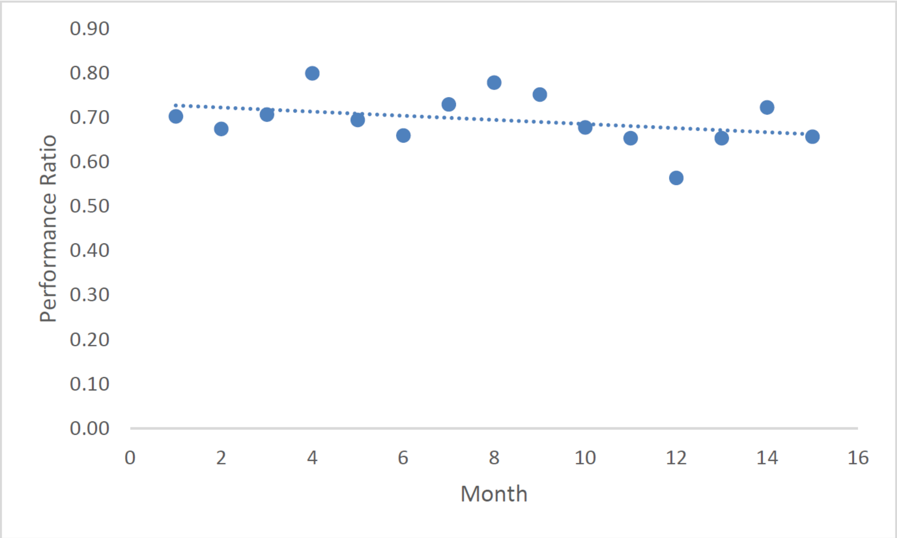

Figure 5. Monthly performance ratio of mono-si PV.

The mono-si PV monthly performance ratio after 16 months of operation is shown in figure 5. Their performance ratio ranged from roughly 60% to 90%. The PV's performance indicates a downward trend, which indicates that it has gotten worse over time. The degradation rate was calculated using linear regression, which produced a result of 2.2%/year, while the CSD technique produced a result of 1.93%/year. With both averages coming in at 2.07 percent per year, the CSD received the lower result for the calculation. The barely differences are occurred in mono-si with the product warranty with 0.8%/year. By this value, their performance could achieve 80% in 25 years of operation.

This enables the PV performance to be diminished. In terms of temperature, CIGS thin film PV would be more durable for hot weather in the tropics, which is 0.35%/oC. Unlike the case with monocrystalline PV which in some references reaches 0.5%/oC. For the comparison, the study about the degradation rate result is shown in table 3.

Table 3. Study about degradation rate in other countries

Reference	Power degradation rated
[7]	In Spain, DR berada dibawah 0.5% (0.27%)
[8]	In Morocco (32o N) : m-si = 0.53 $\pm$ 0.01%/year
[9]	In Ghana (5o N) : m-si = 0.56-2.36%/year
[10]	In Morocco (32o N) : CIS = 3.13%/year
[11]	In Morocco (32o N) : The power degradation rate was of 4.57%/year in the modules with breakage and cracks.
[12]	In India (20o N) : average 1.9%/year (mono-si)
[13]	In Thailand (tropical) : 2.7%/year

To find out how much influence the degradation rate for the economic value of a product, a comparative analysis would be carried out between the levelized cost of energy (LCOE) values before (planning) and after incorporating degradation rate. The result of the calculation and comparation between before and after incorporating the degradation rate are shown in table 4.

Table 4. The levelized cost of energy (LCOE) Calculation before and after degradation rate

	Without degradation rate	With degradation rate	δ
Thin film	Rp 1197/kWh	Rp 1444/kWh	20%
monocrystalline	Rp 1131/kWh	Rp 2006/kWh	77%

Table 4 shows the levelized cost of energy (LCOE) calculations. The levelized cost of energy (LCOE) for CIGS thin film photovoltaic has increased 20% after 16 months operation due to the degradation rate of slightly below 1%/year (0,93%/year). The levelized cost of energy (LCOE) in the CIGS thin film photovoltaic is Rp 1197/ kWh, while it changes to Rp 1444/kWh after incorporating the degradation rate. Differences from the mono-si PV, the levelized cost of energy (LCOE) between without and with the degradation rate are Rp 1131/kWh and Rp 2006/kWh respectively. With the degradation rate of 2,07%/year, it results in the increased of the levelized cost of energy (LCOE) to be 77%. The higher degradation rate would affect the economic value of the PV system for a certain time. The significance increased of the economic value would decrease the future economic value and investment expenses of the photovoltaic system would be higher. It could be indentify that the CIGS thin film PV exhibits a better performance than mono-si PV in the tropics. The technical performance throughout the life cycle also affects the economic value.

4. Conclusion

In this study, the performance and economic analysis between the CIGS thin film PV and monocrystalline silicon has been performed. Both of which have been operated for 16 months. The degradation rate would be deployed as amethod to identify the performance of both photovoltaics. The performance of thin film PV was 5% close to the simulation result but not for the monocrystalline silicon. The thin film PV has a degradation rate of 0.93%/year. It is still slightly above the warranty value promised by the manufacturer, namely a degradation rate of 0.8%/year, while the degradation rate for mono-si is 2.07%/year. A higher degradation rate value of 0.88%/year indicates that PV system would have a performance below 80% at the age of 25 years. After the degradation rate, the economic value Levelized Cost of Energy (LCOE) of the thin film PV has changed by 20%, while for mono-si PV it has changed by 77%. This shows that the large value of the degradation rate would affect the economic value of the operating PV to be decreased. This works remains the first study and the further degradation of the photovoltaic performance would be shown in our future research.

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