# Performance Analysis of PV Modules in Polluted Areas

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November 26, 2024

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***Abstract*—The application of photovoltaic (PV) modules offers numerous benefits in supporting the transition to renewable energy. Despite their many advantages, PV modules have a drawback, one of which is dust that can affect the performance of the PV output. This study was conducted in Baturaja, South Sumatra, near a cement factory, which presents the potential for cement dust particles to settle on PV modules. The study analyzes the performance and efficiency of three PV modules, a comparison that has not been widely explored, as similar studies generally use only two PV modules under two different conditions. The three PV modules examined are: clean PV modules, PV modules left exposed to dust contamination, and PV modules with a dust deposit of 40 grams, compared under the same irradiance and time conditions. Data collection was carried out over a period of four weeks from 09:00 to 16:00. The results indicate that dust deposits impact the performance and efficiency of PV modules. The clean PV module had an output power difference of 0.26 watts compared to the module in real condition, while the clean PV module had a difference of 0.52 watts compared to the dust-deposited module. The PV module in the real condition exhibited better efficiency compared to the module with a 40-gram dust deposit. Additionally, rainy weather and irradiance also have significant effects on PV output performance, but rain has the benefit of reducing dust deposits on PV modules.***

***Keywords—PV Module, Dust, PV Modul Performance, Efficiency***

## I. INTRODUCTION

Indonesia is a tropical region with significant potential for solar energy. The application of solar PV modules in Indonesia is highly suitable for supporting the transition to renewable energy. PV rooftops are one such application of PV modules that are increasingly being developed for implementation in various regions across Indonesia. PV rooftops are installed on rooftops and open areas, which makes them susceptible to dust accumulation on the surface of PV modules. The varying environmental conditions in different regions will affect the amount of dust that settles on the surface of PV panels. This study is conducted in Baturaja, South Sumatra, an area with a high level of cement dust pollution due to its proximity to a cement factory. The research aims to compare three PV modules under different conditions: clean condition, condition with natural dust accumulation, and condition with an additional 40 grams of dust, to assess the impact of dust on the output performance of PV modules.

## II. LITERATURE STUDY

Research on the performance analysis of PV modules has been conducted in recent years. Ikhsan Anwar Fuadi et al. conducted experiments by gradually sprinkling dust ranging from 2 to 30 grams onto an 80 Wp photovoltaic panel to assess its impact on voltage, current, power, and temperature performance of the photovoltaic module [1]. Another experiment compared the conditions of PV panels in two different regions over 6 weeks, finding that PV module efficiency decreased by 15.08% in Islamabad and 25.42% in Bahawalpur [2]. Shaharin A. Sulaiman et al. conducted experiments using dust particles on solar panels with a constant-power light source, showing that dust on the photovoltaic solar panel can reduce efficiency by up to 50% [3]. Rajeshwari Bhol et al. studied the effects of various environmental factors on solar panel performance, including the effects of dust, color, shading, and irradiance. The results indicated that output power and efficiency are affected by environmental factors [4]. Diaz Cipta Pratama et al. analyzed the performance of solar panels under different conditions: clean dry, clean wet, polluted wet, and polluted dry, assessing battery charging time, current, voltage, and power using 10 Wp solar panels [5].

Yingya Chen et al. evaluated the efficiency of photovoltaic systems considering three factors: dust impact, shielding effect, temperature effect, and corrosion impact. The results showed that maximum power could be reduced by about 34% with a dust density of 10 g/m² [6]. Siti Nurjanah et al. studied the impact of dust on PV panel performance by comparing clean PV panels with dusty panels in mining areas over six-months. The result show that the collection of dust and soil can reduce the power output and efficiency [7]. Sarwono et al. compared PV panel performance at high elevation (Semendo Darat Ulu) and low elevation (Tanjung Enim), finding that the average power output at high elevation was 115% higher than at low elevation [8]. Ramadan J. Mustafa et al analyses four environmental factors (the accumulation of dust, water droplets, bird droppings, and partial shading condition) on a PV systems performance. The result show that the accumulation of dust, bird droppings, and partial shading condition can effect to reduce the output PV performance. However, the water droplets can increase the output PV performance at least 5.6% [9]. Shaharin Anwar Sulaiman et al analyzed the effects of the accumulation of dirt such as dust, water, sand, and moss on the performance of PV panels. The experiment used a spotlight as a simulation of sunlight. The results show that external obstructions can reduce PV performance by up to 85% [10]. Md. Nur Alam et al analyzed the impact of soiling and periodic cleaning on a rooftop solar PV plant (industrial). Base on the research, the PV performance increase up to 12% after cleaning base on location and cleaning frequency 3 per month [11].

Referring to the previous studies, this research aims to analyze the output performance of PV modules in areas with high pollutants. This study will be conducted in Baturaja, South Sumatra, which is geographically located between 3°45' to 4°55' South Latitude and between 103°4' to 104°33' East

Longitude. In Baturaja, there is a cement factory that causes cement dust particles to spread throughout the region daily. This research will compare three PV modules under three different conditions to determine the impact of dust on PV module performance.

## III. Methodology

Several factors affect the performance of PV modules, including environmental influences, types of dust, and PV installation factors. Dust comes in various forms, such as cement, sand, soil, ash, and others [12]. PV modules installed in open areas will accumulate dust on their surfaces. The amount of dust particles settling on the surface of PV panels varies by region, depending on surrounding environmental conditions such as wind speed, temperature, humidity, and rainfall. The angle of installation of the PV modules also affects the amount of dust deposition.

The flowchart of this research is illustrated in Figure 1. The study involves reviewing literature related to the research topic, designing the PV modules to be used, installing the PV modules, acquiring and collecting data, analysing the data, and drawing conclusions.

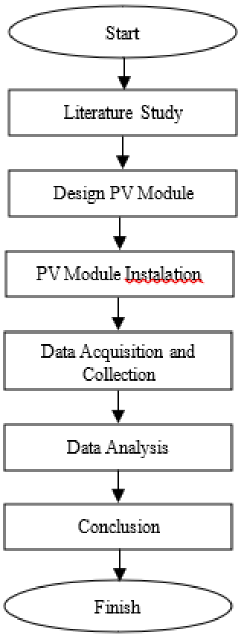


Fig. 1. Flowchart Experiment.

This study uses 100 Wp polycrystalline PV modules, 10 A Solar Charge Controller (SCC), 7 Ah battery, and 7 W DC lamp for output. The installation of the PV system components can be seen in Figure 2. Three PV modules are used to compare three different conditions. The first condition involves the PV module being clean; the panel is cleaned before the experiment. The second condition involves the PV module being left dusty and not cleaned or it can be referred to as the actual condition. The third condition involves the PV module with dust deposits consisting of variations of sand, cement, and soil, with a weight of 40 grams. Irradiance measurements are taken with a Lutron SPM-1116SD irradiance meter. Data collection is conducted over 4 weeks to observe the impact of dust on PV module performance. The PV installation is shown in Figure 3 for the PV modules and Figure 4 for the installation of the Solar Charge Controller, Battery, and DC lamp.

The experiment parameters for measurement are as follows voltage output of PV module, current output of PV module, power output of PV module, and Solar Irradiance. Using that parameters, efficiency in PV power can be calculated using the formula:

$$\eta_{PV} = \frac{P_{PV\ Maks}}{(I \times A)} \times 100\% \qquad (1)$$

Where $P_{PV\ Maks}$ is the power maximum of the PV module, I is the solar irradiation (W/m$^2$), and A is the area of PV module (m$^2$).

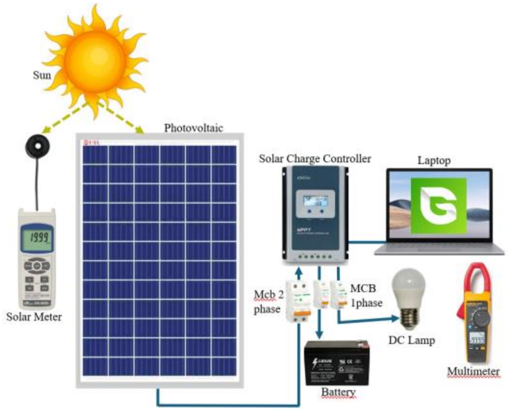


Fig. 2. PV Systems Component and Installation.

The Solar Charge Controller (SCC) is a component that regulates the flow of voltage and current from the solar panel to the battery and the load. its also used to measure the current, voltage, and output power from the PV module. Data collection is carried out by connecting the Solar Charge Controller (SCC) to a laptop using Solar Guardian software.

A multimeter is used to compare the current and voltage measurements from the Solar Charge Controller (SCC) and to ensure that the current and voltage readings from the solar charge controller remain accurate.

The PV module installation for this study is divided into two areas: outdoor and indoor. The outdoor setup (Figure 3) includes cables connected to the indoor panel and three solar panels, where Section A represents the PV module in a clean condition, Section B represents the PV module in its actual condition, and Section C represents the PV module with dust deposits. The indoor setup (Figure 4) consists of the Panel Box, Solar Charge Controller (SCC), Battery, DC Lamp, and Circuit Breaker.


Fig. 3. Experiment PV Module Installation Outdoor.

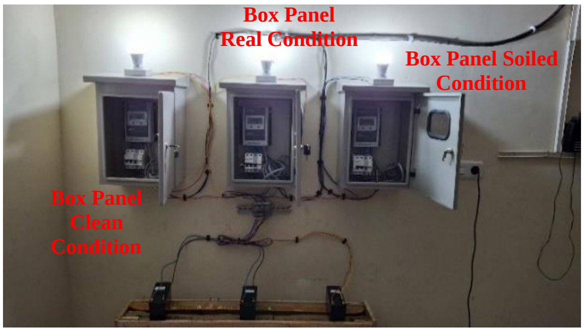


Fig. 4. Experiment PV Module Installation Indoor.

## IV. Result and Discussion

This experiment was conducted in Baturaja, South Sumatra. The PV panels were installed at the PLN ULTG Baturaja office, located approximately 2 kilometers from the PT Semen Baturaja factory, making the PV panels potentially exposed to cement dust. Data collection was carried out over 4 weeks on August 5, 2024, August 10, 2024, August 18, 2024, and August 24, 2024, from 09:00 to 16:00.

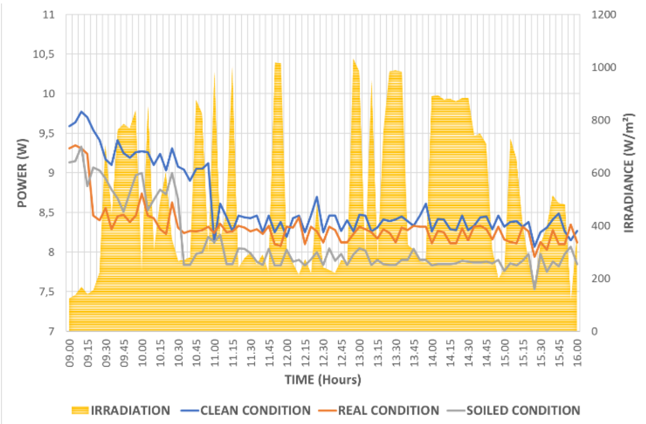


Fig. 5. Power Output from Three PV Panel at Week 1.

Data collection was conducted on August 5, 2024, from 09:00 to 16:00. This experiment used a 40-gram sample of cement dust deposited on one of the PV module (Soiled Condition). Based on Figure 5, the highest power output value was 9.77 W for the clean panel, 9.35 W for the panel in real conditions, and 9.33 W for the panel with soiling condition. The irradiance values were fluctuating due to weather intermittency, with an average irradiance of 502.83 W/m². The clean PV module produced a higher power output than the panel in real conditions and the panel with soiling condition, although the difference in values is only slight.

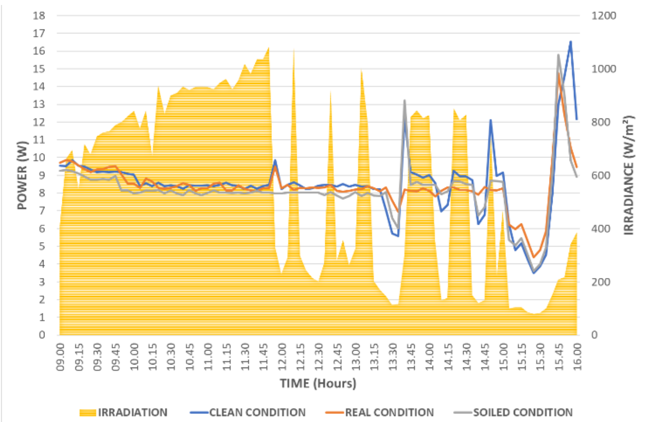


Fig. 6. Power Output from Three PV Panel at Week 2.

Data collection for the second week (figure 6) was conducted on August 10, 2024. This experiment used 40 grams of soil deposited on one of the PV panels. At 14:20, rain occurred, causing the irradiance and power output of all three PV panels to drop drastically, reaching 0.64 W for the clean panel, 0.76 W for the panel in real conditions, 0.64 W for the panel with soil deposits, and the lowest irradiance was 5.5 W/m². At this time, the power output of the clean panel is lower than that of the real condition panel because the current in the real condition panel is higher than in the clean panel. Rain also helps to clean the panel in the real condition, making both panels effectively be in a clean state. The rain significantly affected PV performance; however, it was able to clean the dust or dirt on the PV panels. The average irradiance for the second week's experiment was 359.39 W/m², lower than the average in the first week's experiment due to weather effects.

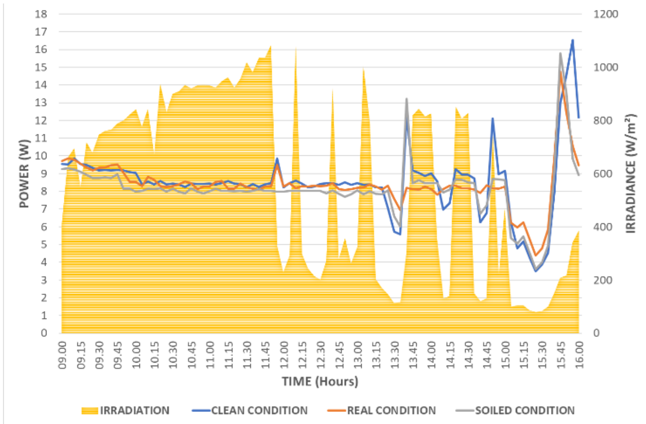


Fig. 7. Power Output from Three PV Panel at Week 3.

Data collection for the third week (figure 7) was conducted on August 18, 2024. This experiment used 40 grams of sand deposited on one of the PV panels. The average irradiance for the third week's experiment was 564.34 W/m², which is higher than the average irradiance in the first and second weeks. The average power output was 8.45 W for the clean panel, 8.38 W for the panel in real conditions, and 8.13 W for the panel with sand deposits. In this third experiment, while the irradiance values fluctuated, the power output of each PV panel remained relatively stable, although the sand deposits still had an impact on PV performance.

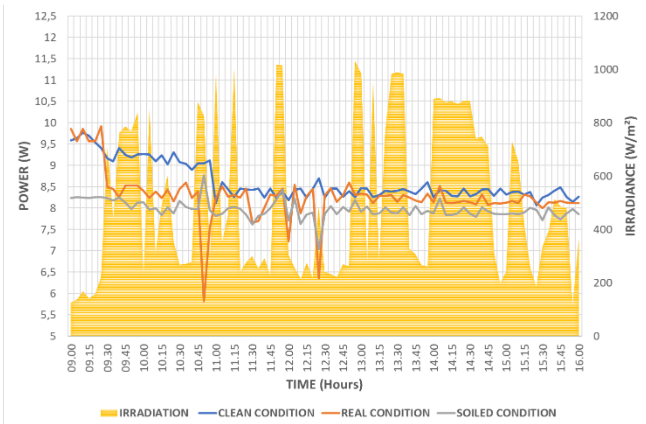


Fig. 8. Power Output from Three PV Panel at Week 4.

Data collection for the fourth week (figure 8) was conducted on August 24, 2024. This experiment used a mixture of cement and soil with a total weight of 40 grams deposited on one of the PV panels. In this experiment, the irradiance values fluctuated, but the power output of all three PV panels remained relatively stable. The average irradiance for the experiment was 502.83 W/m². The average power output was 8.62 W for the clean panel, 8.29 W for the panel in real conditions, and 7.97 W for the panel with cement and soil deposits. At 10:50, the power output for the panel in real conditions decreased, which was due to a reduction in the current supplied to the battery.

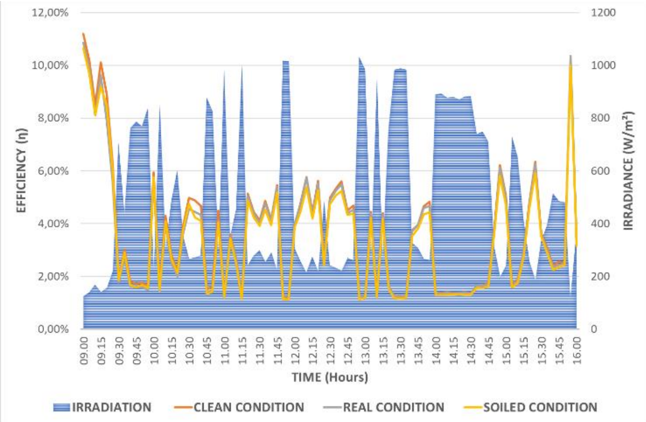


Fig. 9. Efficiency from Three PV Panel at Week 1.

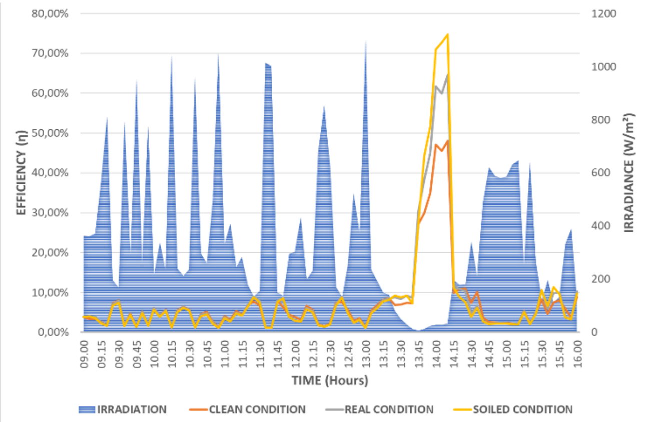


Fig. 10. Efficiency from Three PV Panel at Week 2.

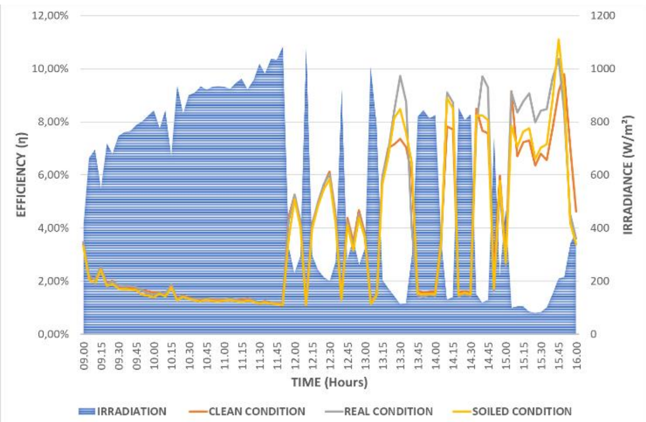


Fig. 11. Efficiency from Three PV Panel at Week 3.

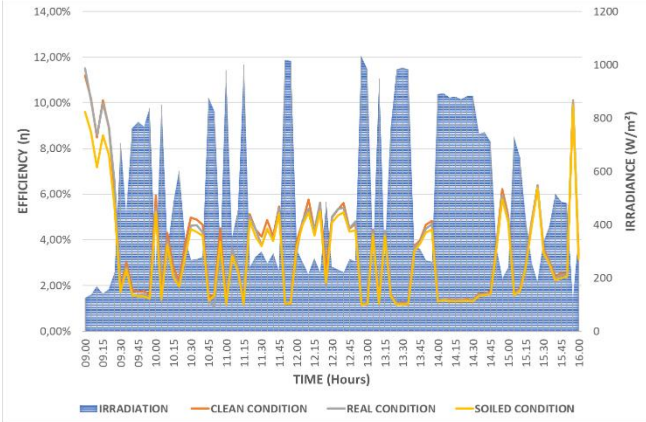


Fig. 12. Efficiency from Three PV Panel at Week 4.

Based on Figures 9 through 12, the efficiency values of each PV panel are similar. When irradiance values decrease, efficiency tends to increase. This occurs because the power output of the PV module remains relatively stable. The average irradiance for each panel is shown in Table 1. The average efficiency values for week 1, week 4, and week 3 are relatively similar, ranging from 3.65% to 3.67% for the clean PV panels, 3.54% to 3.81% for the panels in real conditions, and 3.37% to 3.61% for the panels with dust deposits. However, in week 2, the efficiency values are higher due to the effect of rainy weather. When it rains, irradiance decreases, but the PV performance can still produce good power output, resulting in higher efficiency.

TABLE I. AVERAGE EFFICIENCY OF PV PANELS

| Time | PV Module Condition | | |
|---|---|---|---|
| | Clean Condition | Real Condition | Soiled Condition |
| Week 1 | 3.67% | 3.54% | 3.46% |
| Week 2 | 7.34% | 8.17% | 8.46% |
| Week 3 | 3.65% | 3.81% | 3.61% |
| Week 4 | 3.67% | 3.55% | 3.37% |

Based on Table 1, dust affects PV performance, but in this study, its impact is not substantial over the 4-week experiment period. The efficiency values of the three PV module conditions in the first and fourth weeks do not show significant differences. However, this is also influenced by weather conditions, solar irradiance, and the duration of the experiment.

## V. CONCLUSIONS

This research compares three PV modules in Baturaja, South Sumatra, an area with significant cement pollution. Based on the experiment, the measurements for the clean PV panel showed an average power output of 8.59 W and an average efficiency of 3.66% under clear weather conditions. The real condition PV panel had an average power output of 8.33 W and an average efficiency of 3.63% under clear weather. The soiled condition PV panel had an average power output of 8.07 W and an average efficiency of 3.48% under clear weather. Dust affects the performance of PV output, rainy weather and irradiance also significantly impact PV output performance. Rain can remove or reduce dust deposits on the PV panels, but routine cleaning of PV panels is still recommended, as the absence of dust deposits will improve the PV output performance.

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