Scientific Research Publishing

Energy and Power Engineering, 2025, 17(7), 155-168
https://www.scirp.org/journal/epe
ISSN Online: 1947-3818
ISSN Print: 1949-243X

Impact of Laterite and Silt Dust Deposition on Crystalline Panels under Local Weather Conditions: Case of the Northern Zone of Cameroon

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How to cite this paper: Boussaibo, A., Kiata, E., Kitmo and Abdourahman, G. (2025) Impact of Laterite and Silt Dust Deposition on Crystalline Panels under Local Weather Conditions: Case of the Northern Zone of Cameroon. *Energy and Power Engineering*, **17**, 155-168.
https://doi.org/10.4236/epe.2025.177008

Received: February 4, 2025
Accepted: July 7, 2025
Published: July 10, 2025

Abstract

The use of photovoltaic panels in areas south of the Sahara is dependent on an environment which seems very unfavorable for optimum conversion efficiency (ratio between electrical power produced and the power received at the surface of the solar panel). In this article, monocrystalline and polycrystalline panels having the same electrical characteristics are subjected to local conditions. The panels are exposed to different densities of lateritic and silt type dust ranging from 0 mg/cm² to 25 mg/cm². The panels are exposed under natural irradiance and temperature and measurements are carried out from 9 a.m. to 4 p.m., a period of strong sunlight in the study area. The results obtained from the tests show that the surface temperature of the panels reached 71˚C, the monocrystalline panel is more sensitive to temperature compared to the polycrystalline panel. Beyond 1:15 p.m., the combined effects of the temperature which remains high on the surface of the panel and the irradiance which decreases are not favorable for optimal power production. The tests show that regardless of the type of dust, the monocrystalline panel is more impacted at different dust deposition densities than the polycrystalline panel. Regardless of the type of photovoltaic panel, the results also show that lateritic dust has a greater impact on the conversion efficiency than silty type dust.

Keywords

Solar Energy, Irradiance, Temperature, Dust, Efficiency

1. Introduction

Crystalline silicon solar panels are the most common in photovoltaic applications in countries located south of the Sahara. They represent alone 95% of the market share worldwide [1]. It is accepted in the literature that the conversion efficiencies of commercially available crystalline silicon panels are respectively 18 to 22% for monocrystalline and 15 to 17% for polycrystalline [2]-[4]. These conversion efficiencies are higher than that of amorphous panels which, despite technological advances, their yields peak is 10%. It should be noted that several factors contribute to lowering the conversion efficiencies of crystalline silicon panels. In the area south of the Sahara where the dry season is very long, one of the phenomena that significantly reduces the conversion efficiency is the deposition of dust on the surface of the photovoltaic panels [5] [6].

The accumulation of dust on the surface of the photovoltaic panel can seriously affect its performance [7]. This accumulation of dust depends on factors such as the inclination of the photovoltaic panel, the type of installation, humidity and especially the type of climate prevailing in the area sheltering the solar field [8] [9]. However, the reduction in conversion efficiency depends on the density of accumulated dust, types of dust and the type of photovoltaic cell [10].

As for the density of dust, and according to the work in [9], the accumulation of dust with a density of 6.388 g/m^2 lead to a performance drop (degradation of conversion efficiency) of nearly 15.08% while this drop is estimated at 24.42% for a density of 10.254 g/m^2 respectively in the regions of Islamabad and Bahawalpur in Pakistan [9]. The work in [11] estimates that this reduction can be around 50% when the accumulation duration extends over a slightly longer time. For dust densities ranging from 0.12 g/m^2 to 3.75 g/m^2, the performance drop is respectively 2.3% and 7.5%. The work in [12] conducted a study on the influence of dust deposition on monocrystalline and polycrystalline panels. The results obtained show that for a density of 0.99 mg/cm^2, the monocrystalline and polycrystalline panels present respective performance drops of 20% and 16%. For a density of 3.3 g/m^2, the work in [13] obtained a performance drop of 50% in Senegal. It appears from these works that the greater the density of dust accumulation, the greater the reduction in the conversion efficiency of photovoltaic panels.

Regarding the type of dust, the work in [9] conducted a comparative study of the influence of five types of dust (red earth, ash, sand, calcium carbonate and silica gel) on the performance of multicrystalline panels in OMAN. The results obtained demonstrate that the highest percentage of performance drop is caused by ash, *i.e.*, 25%, while the lowest drop is that of sand, *i.e.*, 4%. The work in [14] conducted a study using four types of dust, namely aggregate, industrial fertilizer, coal and industrial gypsum. The results obtained show that the performance drops are respectively 42.5%, 28%, 64% and 30% for aggregate, industrial fertilizer, coal and industrial gypsum. The work in [15] obtained significant performance drops for different types of fine particles on the surface of the polycrystalline panel, namely cement (89.38%), brick powder (80.33%), white cement (61 .58%), fly ash

(80.46%) and coal (89.42%). It appears from these various works that the impact of dust on the performance of photovoltaic panels also depends on the type of dust used.

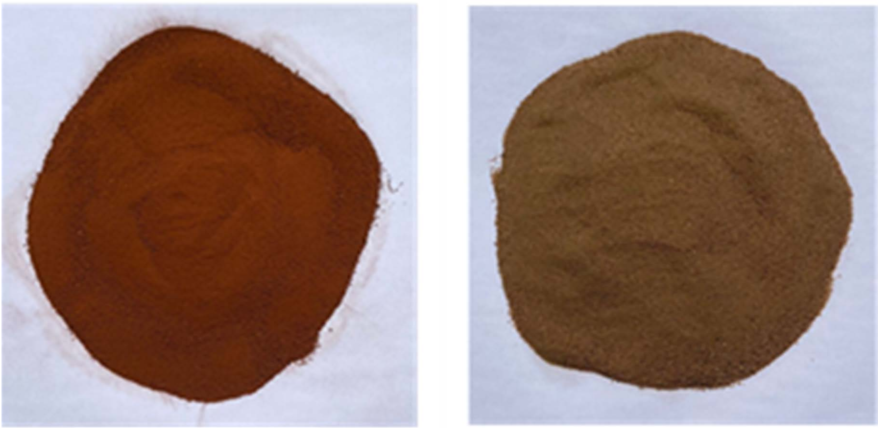
Regarding the type of photovoltaic panel, the work in [16] carried out a comparative study between the polycrystalline panel and the amorphous panel in Egypt. They recorded a performance drop of 33.5% for the polycrystalline panel while this drop is 65.8% for the amorphous panel. According to the work in [17], where he carried out a study of the impact of dust deposition on monocrystalline and polycrystalline panels, it appears that the performance drop noted on the panels is respectively 46.4% and 21.2%. The findings of this study show that the conversion efficiency of the monocrystalline panel is more affected by dust deposits than that of the polycrystalline panel. Dust deposits on the panels significantly reduce the maximum power for both technologies with 77% and 18% respectively for monocrystalline and polycrystalline. The results of the work carried out in [9] show that the performance drop of monocrystalline is 20% while that of polycrystalline is 12%.

In this study, the general observation is that monocrystalline technology would be more sensitive to dust deposits on the surface of the panel than polycrystalline technology. However, the results obtained in [18] with lateritic dust, and under the given handling conditions show that polycrystalline technology is more sensitive than monocrystalline technology. This difference could be explained by the differences in handling conditions, the differences in weather conditions and even the differences in panel manufacturing technologies. Furthermore, we have seen in the previous paragraphs that the performance drop in the panel also depends on the type of dust. It will therefore be wise in this study to use dust from two different areas for a study with monocrystalline and polycrystalline panels in order to remove the ambiguity on the results obtained in [18]; on the other hand, it is interesting to carry out this study in order to enrich the literature with data on the impact of the deposits of certain specific dusts from areas south of the Sahara on the performance of crystalline silicon panels. In addition, it is also interesting to carry out this study because it would help in the choice of the type of panel depending on the type of dust in a specific zone.

2. Materials and Methods

2.1. Sampling Sites

Two sites were selected for the collection of fine particles intended for testing as part of this research work. These are two sites located in the northern zone of Cameroon which is an area south of the Sahara and where the dry season lasts around seven months [19]-[22]. A period long enough for a large quantity of dust to accumulate on the surface of photovoltaic panels. It is a sufficiently sunny area with an average irradiance estimated at 5.8 kW/m^2/day [23] [24]. The first site is located in the Adamaoua region with geographic coordinates: 7˚20' north, 13˚30' east and whose dust is characteristic of the nature of the soil which is lateritic. The second site is located in the Northern region with coordinates: 8˚30' North, 14˚00' East and whose dust results from silty soil. The average annual temperature in the Adamaoua region is 22˚C with a peak reaching 33˚C during the month of March which is the hottest month. The average annual temperature in the Northern region is 29˚C with a peak reaching 40˚C during the month of March which also represents the hottest month [25]. **Figure 1** shows the dust samples taken from the two study sites. The dust collected in Ngaoundere is of a lateritic type and that of Garoua is of a silty type. These dust characteristics are specific to the type of soil found in the two study areas respectively.



(a) (b)

Figure 1. Dust samples: (a) lateritic soil from Ngaoundere; (b) silty soil from Garoua.

2.2. Experimental Photovoltaic Panels

The characteristics of the photovoltaic panels used for the experiments are recorded in **Table 1** below. The electrical characteristics of the two panels are almost identical in order to facilitate comparison studies. The two types of panels are those which mainly equip photovoltaic systems in the study regions, monocrystalline and polycrystalline.

Table 1. Characteristics of photovoltaic panels.

Parameters	Monocristallin	Polycristallin
Model	SA-100	SYM72-6-100P
Maximum power (W)	100	100
Maximum power voltage (V)	17.6	17.8
Maximum power current (A)	5.71	5.62
Open circuit voltage (V)	21	21.8
Short circuit current (A)	6.4	6.05
Number of cells	36	72
Dimensions	1200 × 540 × 30 (mm)	1030 × 680 × 30

STC: 1000 W/m^2; 25˚C; AM 1.5.

2.3. Experimental Setup

Figure 2 presents the experimental setup used for tests. The experiment was conducted using a 100 W monocrystalline panel and a 100 W polycrystalline panel, the characteristics of which are presented in Table 1. The measuring devices used during the tests can be identified on the experiment set-up as follows:

(3): Spectroradiometer
(4): Thermocouple
(5): Solar Power Meter
(6): Multimeters
(7): Solar Panel multimeter

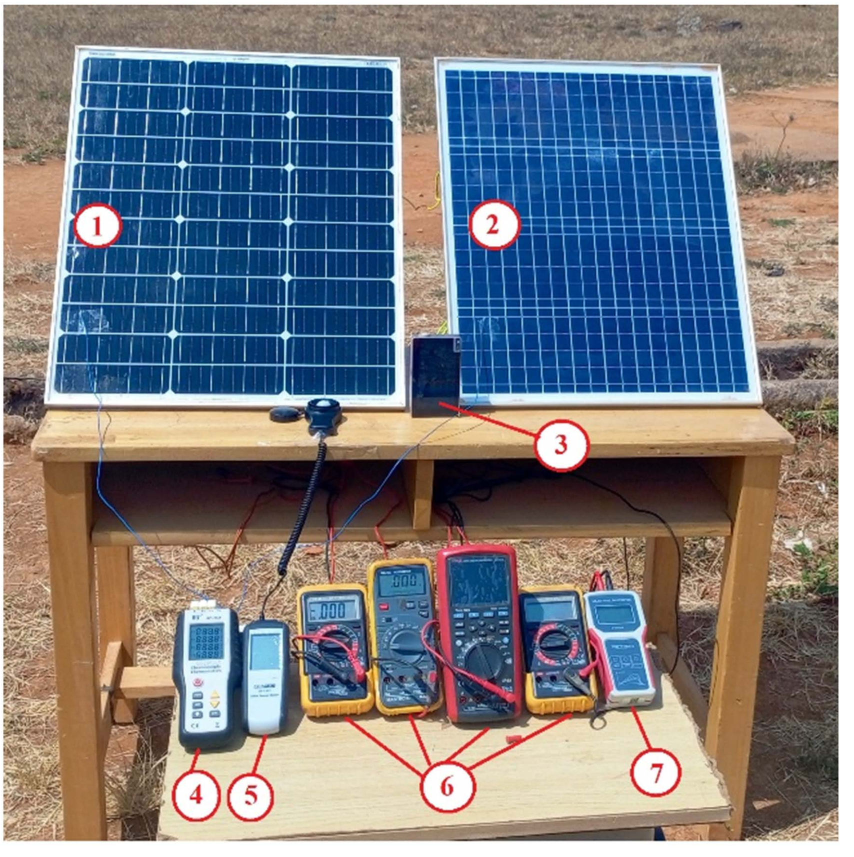


Figure 2. Experimental set-up.

For measurements of electrical parameters, multimeters are used. Temperature probes connected to thermocouple are also used to measure the surface temperatures of photovoltaic panels. But the ambient temperature is measured by the spectroradiometer. The solar Power meter is used to measure the solar radiation. The Solar Panel Multimeter allowed to check the operation of our panels and measure the parameters specific to electrical panels. It can test the maximum power point and open-circuit voltage. It provides automatic and manual MPPT detection, over-voltage, over-temperature, over-current protection. Table 2 summarizes the specifications of measuring equipment that is used in this study.

Table 2. Specifications of measuring devices.

Components	Designation	Specifications
Spectroradiometer	Model	LMS6000
	Wavelength range	380 - 780 nm
	Spectral resolution	±0.2 nm
	Illuminance range	5 - 200,000 lx
	CCT range	1000 - 100,000 K
Solar Panel multi-meter	Model	EY800 W
	Power	5 - 800 W
	Voltage	12 - 60 V
	Current	0 - 35 A
Solar power meter	Model	DT-1307
	Range	1999 W/m^2
	Resolution	1 W/m^2
	Accuracy	±5%
	Sampling time	0.25 s
Thermocouple	Model	HT-9815
	Range	−200˚C to 1372˚C
	Accuracy (T1-T2)	±0.5% rgd + 1˚C
	Temperature Resolution	0.1˚C/˚F for k < 1000˚, 1˚C/˚F for k > 1000˚

3. Methods

3.1. Methodology

The main objective of this work is to assess the impact of fine particles deposition on the surface of monocrystalline and polycrystalline panels. Two dust samples are collected from two different sites. These are lateritic dust and silty dust. Results from experimental work aimed at assessing the density of dust deposited on the surface of panels in areas located in the south of the Sahara show that this density can reach 30 mg/cm^2 [17] [26]. Based on the results of this experimental work, and following preliminary tests, the dust densities selected for testing in this work cover the range from 0 mg/cm^2 to 25 mg/cm^2 in increments of 5 mg/cm^2. The samples are prepared and packaged in boxes, each containing a quantity corresponding to 5 mg/cm^2 for both samples: *i.e.* 24.2 g per boxe. A test day begins by cleaning the panels with clean water and a soft sponge. The panels are then exposed to sunlight and oriented due south at a 22˚ inclination. The measuring devices and loads are then connected to read the following parameters: current, voltage, ambient temperature, panel surface temperature, and irradiance. The dust particles are uniformly spread on the flour strainer whose sieve size is less than

160 micron meter. A test day starts at 9 a.m. and ends at 4 p.m. The chosen time range corresponds to the period of a day of sunshine in the study areas (approximately seven hours of sunshine) [27] [28]. Each test day corresponds to a dust density applied to the panel surfaces. One test series covers exactly six days, which corresponds to densities 0, 5, 10, 15, 20 and 25 mg/cm^2. A total of five test series were conducted:

- One test series allows for a comparative study of clean panels.
- One phase of two test series, where one type of dust is spread on two panels of different technologies.
- Another phase of two test series, where both types of dust are spread on two panels of the same technology.

3.2. Performance Evaluation

Equation (1) allows to determine the power loss factor due to dust deposition as follow:

$$P_{(\%)reduction} = 100 \times \frac{P_{clean} - P_{dust}}{P_{clean}} \tag{1}$$

where P_{pp} represents the power generated by the clean photovoltaic panel and P_{dp} is the power generated by the panel covered with fine particles. The actual conversion efficiency of the panel is given by Equation (2) below:

$$\eta_{module} = \frac{P_{\max}}{(G \times A)} \tag{2}$$

where $P_{\max}$: is the maximum power produced by the panel in Watt; *G*: irradiance in W/m^2; *A*: the surface area of the panel in m^2.

The percentage reduction in yield is given by the following Equation (3) [29]:

$$\eta_{(\%)reduction} = \frac{\eta_{clean} - \eta_{dust}}{\eta_{clean}} \times 100 \tag{3}$$

where η_{clean} is the efficiency of the pure panel then η_{dust} is the efficiency of the panel covered by fine particles.

4. Results and Discussion

4.1. Temporal Profiles of Ambient Temperature and Irradiance

We know that temperature and irradiance are two essential weather factors that have a direct influence on the performance of solar panels. However, as much as the increase in irradiance increases the short-circuit current generated by the photovoltaic cell, the temperature on the surface of the cell leads to a relatively significant drop in the open circuit voltage, and consequently a drop in the power generated. In the area south of the Sahara where we are carrying out this study, the increase in solar irradiance is accompanied by an increase in ambient temperature, unlike in humid tropical areas where the two phenomena do not necessarily have a linked behavior. Analysis of the curves in **Figure 3** shows that the ambient temperature during the test period is an increasing function from 9 a.m., the start time of the readings, until 4 p.m. The irradiance is an increasing function from 9 a.m. until 12 p.m. where it reaches a value of 800 W/m^2 and it decreases to 320 W/cm^2 around 4 p.m. We note that from 1:15 p.m., while the irradiance decreases more quickly, the ambient temperature varies around an average of 35˚C, higher than 25˚C, the standard temperature of the test conditions, which contributes to the continual heating of the photovoltaic panel. We can conclude from the analysis of these curves and in the test conditions that beyond 1:15 p.m., the weather conditions are not favorable for optimal power production because the combined effects of temperature and irradiance are not favorable.

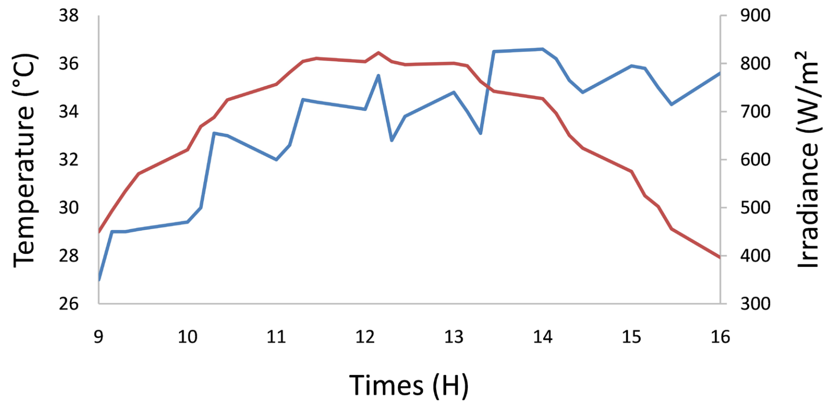


Figure 3. Irradiance and ambient temperature profiles.

4.2. Temporal Profiles of Ambient and Panels Temperatures

Figure 4 shows the ambient temperature and surface temperature profiles of the monocrystalline and polycrystalline panels over time in the study area. We notice that the cell temperatures increase from the start of the tests to reach an optimum around 12 h for the monocrystalline and at 12:15 pm for the polycrystalline. Afterwards, these temperatures gradually drop until the end of the tests at 4 p.m. It can be seen that throughout the testing period, the surface temperature of the monocrystalline panel is higher than that of the polycrystalline panel. The peak temperature on the surface of the monocrystalline panel is 58.1˚C for an ambient temperature of 34.1˚C while the peak temperature of the polycrystalline panel is 53.6˚C. Over the entire test day, the largest temperature difference between the monocrystalline and the polycrystalline is 6.8˚C and recorded at 11 a.m. Considering these results, we note that when the two types of panels are exposed to the same ambient temperature, the rise in temperature on the surface of the monocrystalline panel is greater and faster than that of the polycrystalline panel. This shows that in the study area, the power delivered by the monocrystalline panel will be more negatively affected compared to that delivered by the polycrystalline panel.

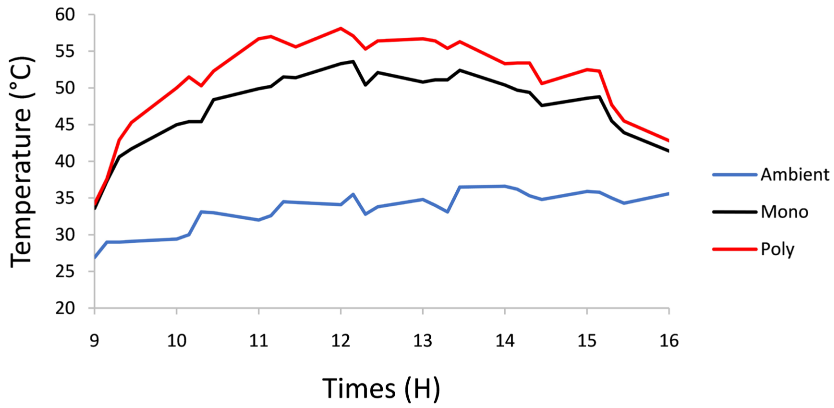


Figure 4. Ambient and panels temperatures profiles.

4.3. Powers Generated by Mono and Poly Panels Covered by the Two Types of Dust

Figure 5, consisting of two rows of 6 graphs, represents the power profiles generated for different densities of lateritic and silty type dust applied to the surface of the two types of monocrystalline and polycrystalline panels. The curve in blue is that of monocrystalline and the curve in red is that of polycrystalline. The curves in the left row are those obtained with lateritic dust while those in the right row are those obtained with silty dust. We observe that for all the graphs, the power generated by the polycrystalline panel is greater than that generated by the monocrystalline panel. This observation is also valid for empty tests, *i.e.* with clean panels. These results tend to call into question the literature data which stipulates that the power generated by the monocrystalline is greater than that generated by the polycrystalline panel with the same electrical characteristics and under the same test conditions. These results can be explained by the influence of the higher temperature gradient on the surface of the monocrystalline panel which would lead to the consequent drop in the power generated compared to that of the polycrystalline panel. We clearly observe the impact of the density of dust deposited on the surface of the panels through the power levels generated.

4.4. Impact of Dust Density on Panels Efficiencies

Figure 6 and **Figure 7** present the profiles of the conversion efficiencies of the monocrystalline and polycrystalline panels covered by lateritic and silty dust respectively. For both types of dust, we note that the conversion efficiency of polycrystalline is higher than that of monocrystalline. We can say in this case that regardless of the type of dust, the monocrystalline panel is more impacted by the deposition of dust than the polycrystalline panel. This result confirms those of the work in [30], but contradicts the results obtained in [18]. Some particularities emerge from the analysis of the profiles of the curves depending on whether it is lateritic or silty dust. Indeed, in the presence of lateritic dust, the gap between the conversion yields between mono and poly gradually narrows and the two

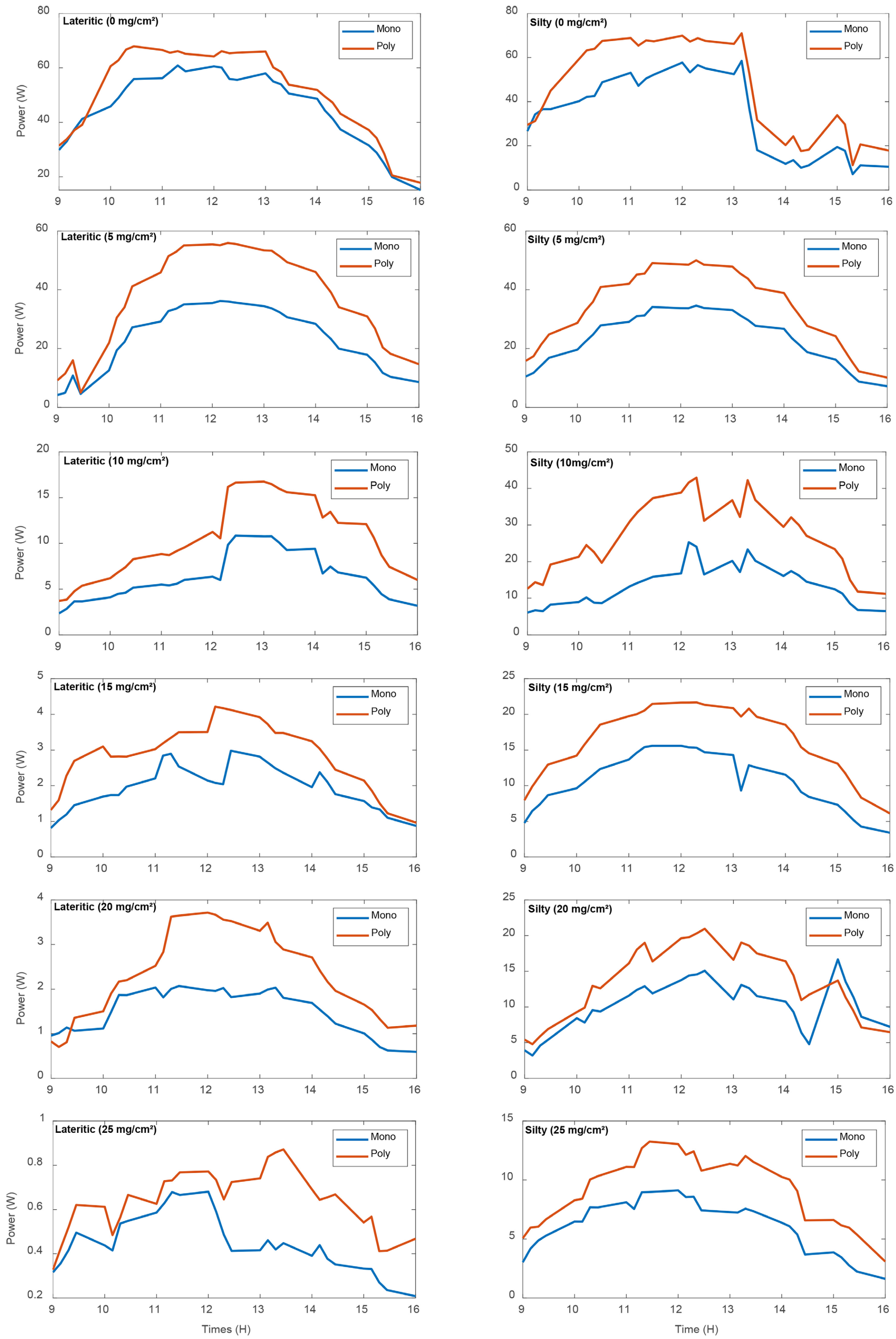


Figure 5. Power profiles at different density values.

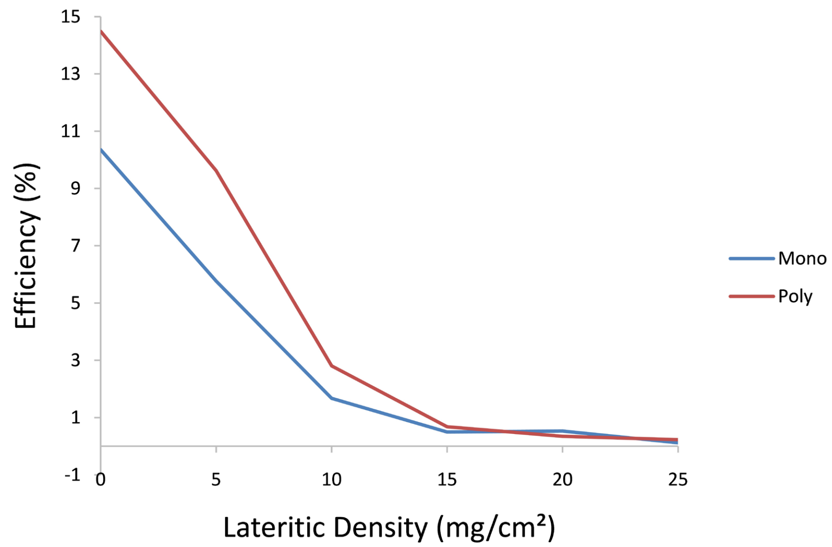


Figure 6. Solar panel efficiency as a function of Lateritic density.

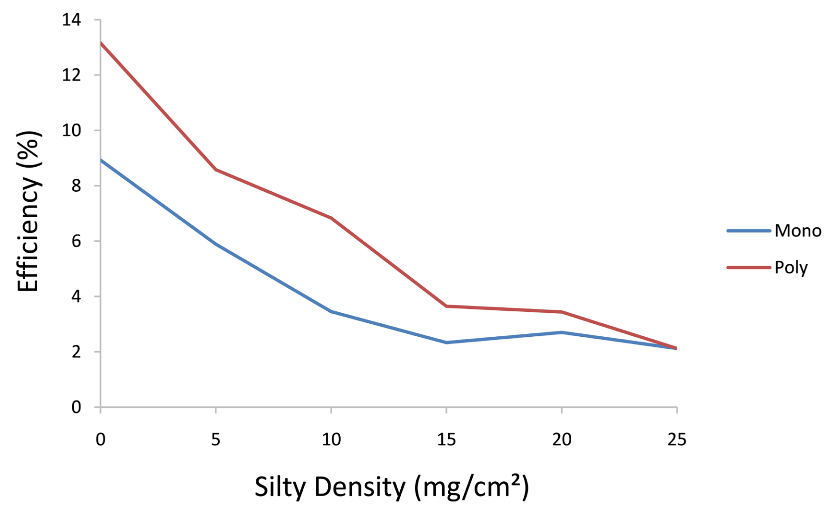


Figure 7. Solar panel efficiency as a function of silty density.

yields become almost equal and very low for densities greater than 15 mg/cm^2. As for silty dust, we also notice that the gap between the conversion yields is narrowing but they become almost equal and very low at 25 mg/cm^2. Considering these results, we can see that lateritic dust has a greater impact on the conversion efficiency than silty dust.

5. Conclusion

The results obtained in this research work constitute a solid basis for decision support tools in the context of applications using photovoltaic energy, for areas located south of the Sahara in general and in the study area in particular. It has been shown that the monocrystalline panel is more sensitive to temperature than the polycrystalline panel. However, regardless of the type of panel, the combined effects of irradiance and temperature are not favorable to optimal production of energy beyond a certain time. When analyzing our results, regardless of the type of dust, the monocrystalline panel is more impacted by dust deposition than the polycrystalline panel. However, it should be noted that additional tests not covered by this paper could reinforce this result or demonstrate that the observation made [18] is influenced by other parameters such as the surface properties of the panels or the variation in the manufacturing. It should also be noted that lateritic dust has a greater impact on the conversion efficiency of solar panels than silty dust, regardless of the type of solar panel. The results obtained in this article are specific to the test conditions and the study environment. Any use of these results for a comparative or extensive study must take into account.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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