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EFFECT OF THE TYPE AND AMOUNT OF SEDIMENTED SAND AND CLAY DUST ON THE ENERGY OF THE SOLAR PANEL

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Background: The application of solar energy utilization in the world to generate electricity is established. The use of solar panels to generate electricity has witnessed steady scientific progress and plays a significant role in confronting environmental pollution. For solar panels, the efficiency depends to a large extent on the relationship between the solar radiation reaching the Earth's surface and the dust layer covering the panels. In the case of a solar panel collecting a large amount of dust in its working place, the solar radiation is first diluted through the dust layer before it reaches the panel. This is the main reason for the decrease in the panel's efficiency. **Objectives:** It is of utmost importance to study the effects of dust on the design of photovoltaic devices. The potential power reduction of panels due to dust is a pressing issue, with immediate consequences for the operation and number of panels in large solar power plants. This work aims to urgently study the effect of dust accumulation on the front surface of solar panels. **Methods:** The experiment is being conducted on two different solar panels: the first is monocrystalline with a power of 200 W, and the second is polycrystalline with a power of 280 watts. Two types of dust – sand and clay – are being used in quantities ranging from 5 to 25 g. **Results:** The introduction of sand dust led to a substantial decrease in the energy output of the monocrystalline solar panel, ranging from 3.3% to 7.5 %. Similarly, the use of clay dust resulted in a significant energy drop of 4% to 8%.While the energy of the polycrystalline plate decreased between 2.5% to 6.7% when using sand dust and between 3% to 7.1% when using clay dust. **Conclusion:** Our research uncovers the negative impact of dust on the efficiency of solar panels, particularly in the case of monocrystalline panels and those exposed to clay dust. This opens up avenues for further research and exploration in the field of solar technology.

Keywords: solar panel; dust; efficiency; energy; electricity.

INTRODUCTION

Climate change has forced a reliance on renewable energy sources such as solar energy, and this shift is evident with the rapid expansion of solar panels in urban areas around the world (Olabi et al., 2022). However, the interaction between solar panels and dust reduces the efficiency of energy conversion processes. Methods for preventing dust accumulation and developing resistance to atmospheric dust are under constant investigation by scientists in the field of civil engineering (Chaichan & Kazem, 2024). Gupta and others have studied the effect of dust on solar panels. The researchers focused on the effect of dust deposition on the electrical, optical and thermal properties of a photovoltaic power unit. (Gupta et al., 2019). In another study, the impact of climatic conditions on the performance of a photovoltaic power unit, especially the impact of dust pollution, was studied. The experimenters concluded that dust deposition has a significant impact on the photovoltaic (PV) module's performance because it reduces the light transmittance of the PV module's surface coating (Said et al., 2018). The effect of dust accumulation on surfaces such as solar panel glass can lead to a decrease in the permeability of incident solar radiation, which consists of a scattering or reflection ratio of radiation and physical clogging of some mirrors and lenses (Hachicha et al., 2018). Dust particles larger than the surface roughness show the classical mechanisms of light escape, such as reflection and refraction losses, which occur on the surface of the plate. Particles smaller than the surface roughness will occupy the valleys and prevent the escape of light upwards; they are usually absorbed. The dust size range can, therefore, affect the amount of light scattered, absorbed or reflected (Panat & Varanasi, 2022). Larger particles may occupy surface features and scatter incident sunlight through physical processes. There is a clear correlation between the physical and chemical properties of dust and how these properties affect the adsorption and adhesion properties of dust on panel surfaces. This indicates how dust from different geographical regions affects the performance of solar panels to different degrees (Wang et al., 2018). Dust levels can also change with the season. Some results indicate that dust levels in urban environments are four times higher than in rural ones. These results are important for considering iterative methodologies for cleaning solar panels. The accumulation of dust on solar panels has become a pressing issue and a significant challenge facing many countries around the world. Dust builds up on the surface of solar panels, forming a layer that detrimentally impacts the radiation that hits the solar panel, thereby reducing the amount of energy produced. This urgent issue requires immediate attention and action. The cleaning efficiency is about 85%, indicating that regular cleaning will be useful only in areas with low pollution. However, the potential for self-cleaning panels offers hope for areas with higher pollution levels. As dust particles will be deposited over time, the solar panel may be designed to clean itself, providing a promising solution to the dust problem.

In this paper, the effect of dust on the efficiency of two solar panels will be studied: the first single-crystal and the second multi-crystal. Two types of dust, dune sand and clay dust, were used in this study to represent the variety of dust particles that can affect solar panels. The results of the study are expected to provide a crucial understanding of the impact of these two variables on the profitability of a solar panel. In addition, the results of the current study are expected to contribute to the development of valuable solutions to the dust problem, highlighting the importance of this research in the field of renewable energy and civil engineering.

MATERIALS AND EXPERIMENTAL METHODS

The research methodology involved a series of controlled experiments to study the impact of the type of solar panel and dust on the efficiency of the energy produced by the solar panel.

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Materials

Monocrystalline solar panel

Monocrystalline silicon (mono-Si) (Table 1). These panels are produced by cutting silicon ingots from a silicon ingot formed by the Czochralski method, which produces high-quality silicon. The cells have uniformly rounded edges. Since solar cell efficiency is the highest for this type of technology and its lifespan is also long, it can be used in areas suitable for large solar power plants and clustered systems. The cost is also higher compared to polycrystalline technology (El-Atab et al., 2022).

Table 1. Monocrystalline solar panel characteristics

Electrical parameters	Values
Maximum Power	200
Optimum Operating Voltage	21 V
Optimum Operating Current	9
Open Circuit Voltage	24.1 V
Short Circuit Current	10.9 A
Cell Efficiency	21
Maximum Series Fuse Rating	15

Polycrystalline solar panel

Polycrystalline silicon (p-Si) (Table 2). These panels are made from raw silicon, generally made into wafers. Cubic-shaped silicon is obtained by casting molten silicon into molds and then solidifying it. Then it is made into solar cells. It has low conversion efficiency and a low useful life. It is generally used for rooftops, sunlight-based lighting systems, and other small installations in small towns and communities (Kazem et al., 2022).

Dust

The crust of the Earth is covered by dust particles with a variety of different compositions. Common sources of dustincludes oil, sea spray, pollen, volcanic ash, biological matter, and industrial pollutants. Dust emitted from Earth's surface is generally composed of crustal materials, such as clays and silts containing oxides, while other particles can absorb and scatter significant fractions of light, such as soot and biological matter. Various physical properties of suspended dust can influence its adhesion on surfaces. In this experiment, sand and clay are used.

Table 2. Polycrystalline solar panel characteristics

Electrical parameters	Values
Maximum Power	280
Optimum Operating Voltage	36.01 V
Optimum Operating Current	7.78A
Open Circuit Voltage	44.44 V
Short Circuit Current	8.45 A

Clay. The clay used in the experiments is available in all the territories of the Adrar region of southern Algeria. It is used in the field of conventional construction . It is characterized by a density of 2.6 g/cm^3. It consists mainly of the element silica 63%. It adheres strongly to water because its composition is 54% silt, less than 0.02 mm. It absorbs water very much. Table 3 shows the characteristics of the clay used.

Sand. It uses dune sand, which is found in most desert areas. It is characterized by fine sand pan with a density of 1.46 g/cm^3. It is characterized by its freedom from organic substances and a high percentage of SiO_2 93.66%. The grain size is less than 1 mm. Table 4 shows the characteristics of the sand used.

Over the past decade, experimental studies have been performed to validate the negative effect of dust on the efficiency of solar panels. These studies have explored a wide range of configurations, including solar panels oriented at different angles, solar panels at different positions, and solar panels both cleaned and uncleaned. Most of these studies have been dedicated to laboratory investigations. The dust effects have been mainly tested in a controlled environment by simulating dust conditions to observe the decrease in energy output.

Table 3. Clay dust properties

Geotechnicals properties (Belaidi et al., 2022)		Chemical composition (Abbou et al., 2020)	
Sand >0.02 mm	9%	SO_4^{-2}	0.41%
Silt 0.020 – 0.02 mm	54%	$CaCO_3$	3.6%
Clay <0.002 mm	37%	Cl^-	0.14%
Liquid limit WL	81%	SiO_2	63%
Plastic limit WP	34%	Al_2O_3	16%
plastic index IP	47%	Fe_2O_3	7%
VB	8	MgO	2.4%
Specific density γs	2.6 g/cm^3	Other	7.46%

Table 4. Sand dust properties

Geotechnicals properties (Abbou et al., 2020)		Chemical composition (Fidjah et al., 2024)	
Sand equivalent	36.49%	SiO_2	93.66%
Specific density	2.5g/cm^3	Al_2O_3	1.52%
Apparent density	1.46 g/cm^3	Fe_2O_3	0.59%
Finesse Model	2.79	CaO	1.14%
		K_2O	0.43%
		Na_2O	0.13%
		MgO	00%
		SO_3	0.05%

Experimental methods

Calculation of solar radiation on an inclined surface

To calculate the solar radiation on an inclined surface, the relation 1 is used:

$$R = R_e \cdot \cos \propto, \quad (1)$$

R is the intensity of solar radiation, R_e is the intensity of solar radiation on the vertical surface, $\propto$ is the angle of the inclined surface.

Characteristics of the place

The Adrar region is considered a hot region; in summer, the temperature reaches above 50 degrees. This area is chosen for experiments combining the effect of heat and the impact of dust. The location of solar panels is characterized by the following indicators:

– height from the sea 279 meters;
– latitude: 27.8667, longitude: -0.283333;
– the angle of inclination of the plates is 40 degrees north.

The research experiment was conducted between 13:00 and 14:00 pm. Solar radiation was measured first before adding dust. Figure 1 represents the change in the value of solar radiation during the experiment days at 13:00 pm. The amount of dust was changed and distributed evenly on the solar panel.

Before the experiments began, the solar panels were subjected to a thorough meticulous cleaning process to ensure the accuracy of the results. The energy generated was then measured.

The energy produced by the solar panels was measured with precision both before and after the application of the dust, be it clay or sand, for a duration of 10 minutes.

Following the measurement, the solar panels were cleaned again. Then the dust, whether clay or sand, was replaced and the measurement was repeated for another 10 minutes, which confirms the reliability of the results.

On the first day, 5 g of dust (clay or sand) was added; on the second day, 10 g of dust (clay or sand); on the third day, 15 g of dust (clay or sand); and then the value of the energy produced was measured.

On the fourth and fifth days, solar radiation was measured before the experiments; then 20 g of dust (clay or sand) were added on the fourth day and 25 g of dust (clay or sand) on the fifth day, respectively, and the energy produced was measured again. Table 5 provides information about the experiments.

Table 5. Organizational preparation for the experimental study

No	Dust indicator	Dust type	Polycrystalline solar panels		Monocrystalline solar panels		Experience
1	Amount of dust, g	Clay	5	5	5	5	E1
		Sand	5	5	5	5	E2
2		Clay	10	10	10	10	E3
		Sand	10	10	10	10	E4
3		Clay	15	15	15	15	E5
		Sand	15	15	15	15	E6
4		Clay	20	20	20	20	E7
		Sand	20	20	20	20	E8
5		Clay	25	25	25	25	E9
		Sand	25	25	25	25	E10

RESULTS AND DISCUSSIONS

Figure 1 illustrates the fluctuation in solar radiation levels during the course of conducted experiments. Research region, known for its high temperatures, receives abundant solar radiation, making it an ideal location for this research.

Figure 2 illustrates the significant impact of sand and clay dust on the energy value of a monocrystalline solar panel.

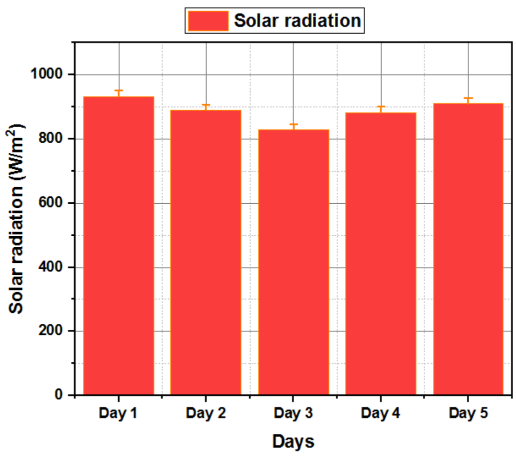

Figure 1. Solar radiation values

This visual representation highlights the strong dependence of solar panel efficiency on dust pollution and the practical significance of the current research.

Prior to the commencement of the experiments, a high energy value was observed, which notably decreased after the introduction of dust.

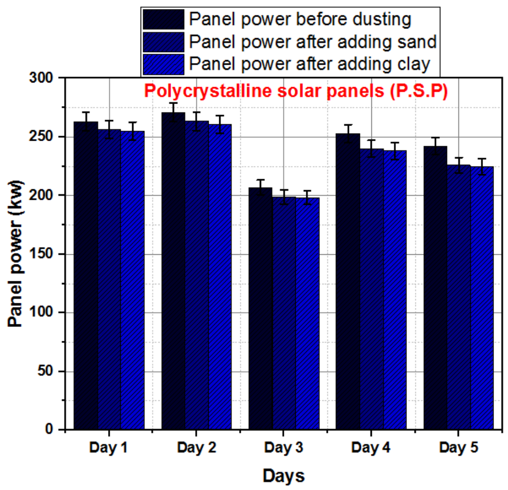

Figure 2. Effect of sand and clay dust on the efficiency of a polycrystalline solar panel

In the monocrystalline solar panel

When adding sand dust:

– **the first day**: the intensity of solar radiation 933 W/m^2;
– the solar panel capacity decreases from 193 kW to 186.6 kW by 3.3%;
– **the second day**: the intensity of solar radiation 890 W/m^2;
– the solar panel capacity decreases from 185 kW to 176.6 kW by 4.5%;
– **the third day**: the intensity of solar radiation 830 W/m^2;
– the solar panel capacity decreases from 162 kW to 152.6 kW by 5.8%;
– **the fourth day**: the intensity of solar radiation 883 W/m^2;
– the solar panel capacity decreases from 175 kW to 163.3 kW by 6.7%;
– **the fifth day**: the intensity of solar radiation 910 W/m^2;
– the solar panel capacity decreases from 164 kW to 152 kW by 7.5%.

When adding clay dust:

– **the first day**: the intensity of solar radiation 933 W/m^2;
– the solar panel capacity decreases from 193 kW to 185.2 kW by 4%;
– **the second day**: the intensity of solar radiation 890 W/m^2;
– the solar panel capacity decreases from 185 kW to 174.8 kW by 5.5%;
– **the third day**: the intensity of solar radiation 830 W/m^2;
– the solar panel capacity decreases from 162 kW to 151.6 kW by 6.4%;
– **the fourth day**: the intensity of solar radiation 883 W/m^2;
– the solar panel capacity decreases from 175 kW to 162.4 kW by 7.2%;
– **the fifth day**: the intensity of solar radiation 910 W/m^2;
– the solar panel capacity decreases from 164 kW 150.9 kW by 8%.

Figure 3 represents the change in the energy value of the polycrystalline solar panel when sand and clay dust are placed. A decrease in the power of the solar panel is observed with an increase in the amount of dust.

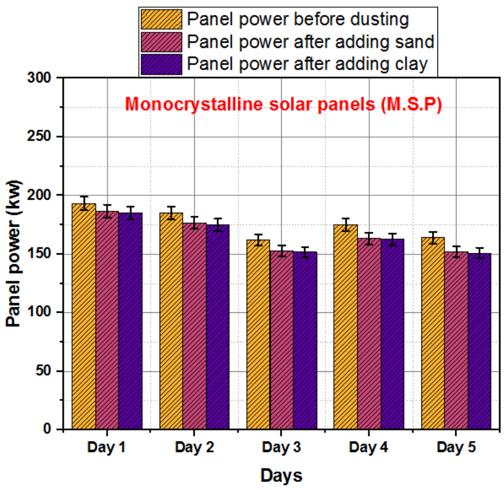

Figure 3. Effect of sand and clay dust on the efficiency of a monocrystalline solar panel

In a polycrystalline solar panel

When adding sand dust:

– **the first day**: the intensity of solar radiation 933 W/m^2;
– the solar panel capacity decreases from 263 kW to 256.4 kW by 2.5%;
– **the second day**: the intensity of solar radiation 890 W/m^2;
– the solar panel capacity decreases from 271 kW to 263 kW by 2.8%;
– **the third day**: the intensity of solar radiation 830 W/m^2;
– the solar panel capacity decreases from 207 kW to 198 kW by 4%;
– **the fourth day**: the intensity of solar radiation 883 W/m^2;
– the solar panel capacity decreases from 253 kW to 239.8 kW by 5.2%;
– **the fifth day**: the intensity of solar radiation 910 W/m^2;
– the solar panel capacity decreases from 242 kW to 225.8 kW by 6.7%.

When adding clay dust:

– **the first day**: the intensity of solar radiation 933 W/m^2;
– the solar panel capacity decreases from 263 kW to 255 kW by 3%;
– **the second day**: the intensity of solar radiation 890 W/m^2;
– the solar panel capacity decreases from 271 kW to 260.7 kW by 3.8%;
– **the third day:** the intensity of solar radiation 830 W/m^2;
– the solar panel capacity decreases from 207 kw to 198.3 kw by 4.2%;
– **the fourth day**: the intensity of solar radiation 883 W/m^2;
– the solar panel capacity decreases from 253 kW to 238 kW by 5.9%;
– **the fifth day**: the intensity of solar radiation 910 W/m^2;
– the solar panel capacity decreases from 242 kW to 224.8 kW by 7.1%.

A monocrystalline plate absorbs sunlight better than a polycrystalline plate, which improves the efficiency of the monocrystalline plate. This explains that the percentage of energy reduction is lower in a monocrystalline plate compared to a polycrystalline plate despite the difference in the amount and type of dust. This is consistent with previous research (Hidayat et al., 2022; Benghanem et al., 2023).

When the plates are covered with sand or clay dust, the efficiency of the plates decreases between 2.5% and 8%. This decrease is due to the blocking of sunlight on photovoltaic cells. These results are consistent with previous research (Dida et al., 2020; Chaichan & Kazem, 2024). The decrease in energy value is even greater when the dust is clayey. This is explained by the fact that Clay is denser than sand and thus blocks the sun's rays more than sand (Coşgun & Demir, 2022).

Figure 4 represents the energy change in the two plates when the amount of sand and clay changes.

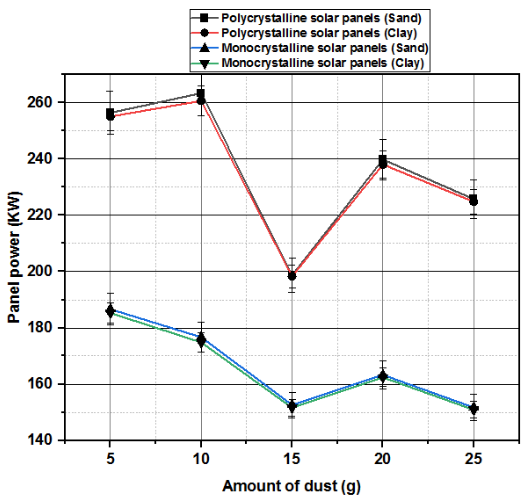

Figure 4. The energy in the two solar panels changes when the amount of sand and clay changes

Current analysis of the energy change curve reveals a direct correlation between the amount of dust and the efficiency of the solar panels. This practical insight underscores the importance of regular panel maintenance, as the longer a panel remains dirty, the less efficient it becomes. This finding has been consistently demonstrated by several researchers in the field.

In search of Alnasser et al. (2020) the accumulation of dust consisting of (more than 50%) silicon oxides (sand), cement and gypsum was studied for 3 months on the profitability of a photovoltaic (PV) unit. The researchers noted that these materials reduce the efficiency of photovoltaic panels (Alnasser et al., 2020). And in another study, the effect of dust accumulation in the photovoltaic system was evaluated quantitatively. The researchers proposed six representative dust pollutants (ash, laterite, stone dust, sand, coal powder and cement). The accumulation of dust has a significant inhibitory effect on the energy production in photovoltaic panels (Fan et al., 2021).

Existing dust mitigation strategies

One of the most effective ways to counter the reduced efficiency of solar panels due to dust accumulation is regular cleaning. This practice not only maintains the panels but also significantly improves their energy conversion efficiency. This approach is designed to mitigate the impact of dust on energy production. It involves the use of both manual and mechanical methods, with the latter being adaptable to various settings, including centralized or off-grid systems, each with its unique water access requirements (Derakhshandeh et al., 2021).

Chemical treatments play a significant role in maintaining the efficiency of solar panels. These treatments, such as the application of superhydrophobic and anti-reflective coatings, are designed to prevent the accumulation of fingerprints or dirt during normal use of the solar module. Recent developments in these treatments aim to repel or significantly reduce the adhesion of dust particles to the module's surface, further enhancing the panels' performance (Amjad et al., 2024).

The importance of studying the effect of dust on the efficiency of solar panels

The area where the experiments are being conducted is known for the high temperature in the summer, which further reduces the panel power; in addition to the impact of dust on solar panels when using photovoltaic systems, it is known that the efficiency of solar panels decreases due to heat, sand and dust that adhere to the surfaces of the panels over time, where the current production decrease reaches 8%.

For instance, in a region with high dust accumulation, the efficiency of solar panels could decrease by as much as 8%. This decrease in efficiency could lead to a significant reduction in power generation, exacerbating the energy shortage in arid regions. The decrease in the amount of solar photovoltaic energy reaching its cells is noticeable in arid regions, as regions face acute problems of energy shortage due to the accumulation of dust on their solar cells. Annual power generation losses can reach about 35% and can occur both on working solar farms and on newly built farms. Such a waste of energy is the result of the accumulation of solar dust on photovoltaic cells, which convert solar energy into electrical energy. Soluble salts from dust cause additional problems when the salts are knocked out by dew during the night and stick to the windshield. High temperatures the next day lead to the deposition of salt residues. High temperatures burn salts and reduce the efficiency of solar panels.

Understanding the impact of desert dust deposition on the performance of photovoltaic solar panels has become critical due to the increase in the number of photovoltaic parks in arid desert locations. However, there is a lack of available technical data on dust interactions with the surface. Researchers should be aware of a common limitation of traditional laboratory or indoor studies on these interactions, as the deployment of solar panels based on environmental dust may differ significantly. To ensure the reliability of laboratory results, additional dust research and studies should largely include constant exposure to real desert dust in the open air. Then, it will be possible to determine whether the results of our laboratories recorded under controlled conditions are effectively comparable with such panels and can be installed in real desert areas.

CONCLUSION

This paper delved into the effect of dust type and quantity on two monocrystalline and polycrystalline solar panels in the Adrar region of Southern Algeria. The results revealed that dust accumulation, whether clay or sand, led to an energy decrease of 2.5% to 7.1% for the polycrystalline panel and 3.3% to 8% for the monocrystalline panel, with a more significant impact from clay dust. Thus, the current study further developed the scientific approach to the development of effective strategies for the use of alternative energy, and also confirmed the theory of the need to take into account the characteristics of the region (such as the type and intensity of possible dust) when calculating the design reproducibility of solar panels energy. The study showed that for dusty regions it is preferable to use such monocrystalline panels due to lower losses in dusty conditions. The study's findings underscore the importance of further research on the quantity and type of dust in various tests and climatic conditions, particularly in developing effective dust self-cleaning strategies. This knowledge is crucial as it can help mitigate the significant decline in photovoltaic power production caused by surface pollutants.

Author's statements

Contributions

All authors contributed to the study's conception and design. Conceptualization: S.A., F.A.; Data curation: F.A.; Formal analysis: S.A.; Investigation: S.A., F.A.; Methodology: S.A., F.A.; Project administration: S.A.; Visualization: F.A.; Writing – original draft: S.A., F.A.; Writing – review & editing: F.A.

Declaration of conflicting interest

The authors declare no competing interests.

Financial interests

The authors declare they have no financial interests.

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Data availability statement

No data were used for the current study.

AI Disclosure

The authors declare that generative AI was not used to assist in writing this manuscript.

Ethical approval declarations

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