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# Performance Enhancement of Solar Modules in Arid Climates: Dust Mitigation Strategies in Ghardaïa, Algeria

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**Abstract**

This study explores how different dust reduction and cleaning methods affect the performance of monocrystalline silicon solar modules in the harsh desert conditions of Ghardaia, Algeria. Six identical solar modules with maximum power point tracking (MPPT) technology were tested to compare three cleaning techniques: water cleaning, cloth cleaning, and a mixture of water and sodium bicarbonate. The water-sodium bicarbonate solution proved highly effective, improving cleaning efficiency by 75% over 10 days. This significant improvement is due to the solution's ability to thoroughly remove dust and dirt that can reduce solar panel performance. The study highlights the importance of choosing the right cleaning methods and scheduling them properly to boost energy output, lower maintenance costs, and ensure reliable solar energy production in dry and dusty environments

**Keywords:** Solar; Desert conditions; MPPT; Experimental platform.

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## 1. Introduction

Global warming has become one of the most pressing issues of the 21st century, with rising global temperatures serving as a stark reminder of the ongoing impacts of climate change. Since the Industrial Revolution, average global temperatures have increased by approximately 1.1 degrees Celsius, causing significant disruptions to ecosystems and human livelihoods. In response to these challenges, the transition to renewable energy sources has gained momentum, with solar power playing a pivotal role in reducing greenhouse gas emissions.

Desert regions, characterized by abundant sunlight and vast open spaces, are ideal for the installation of large-scale solar power plants. However, these environments present unique challenges, particularly the accumulation of dust on photovoltaic (PV) modules. Dust deposition can severely impair the performance of solar panels, reducing energy output and increasing maintenance requirements. This issue is especially prevalent in arid regions such as the Middle East and North Africa, where frequent cleaning is essential to maintain efficiency.

To address this problem, various cleaning techniques have been developed, including water-based methods, mechanical brushing, anti-soiling coatings, air-blow cleaning, and advanced solutions such as electrostatic cleaning. The effectiveness of these methods depends on multiple factors, such as dust particle size, weather conditions, module orientation, and local industrial activities.

This study focuses on evaluating the performance of Mono- Si solar modules under harsh desert conditions. It examines the impact of three cleaning methods: water-cleaning, cloth cleaning, and cleaning with a water-sodium bicarbonate mixture, on the efficiency and durability of PV modules. By identifying the most effective cleaning strategies, this research aims to enhance the performance of solar installations in arid climates and contribute to the sustainable development of solar energy systems in challenging environments.

## 2. Materials and Methods

The experimental platform was established at the Applied Research Unit in Renewable Energies (URAER) in Ghardaïa, southern Algeria (coordinates: 32°34′ N, 3°41′55″ E), situated 15 km from the city center. This region experiences a dry and hot climate during summer and cold conditions in winter, with temperatures ranging from -5°C to 50°C. The area also receives significant solar radiation, ranging from 800 to 1100 W/m², making it an ideal location for testing solar energy equipment under harsh environmental conditions [6].

The platform features six photovoltaic (PV) modules utilizing monocrystalline silicon (Mono-Si) technology. These modules were installed and evaluated on an experimental photovoltaic system located at URAER (Figure 1). The modules were mounted on supporting structures with a southward orientation and a tilt angle of 32°, corresponding to the site's latitude. The technical specifications of the PV modules, as provided by the manufacturer, are summarized in Table 1.

TABLE I. Electrical Characteristics of the PV Modules

| Parameters | Value |
|---|---|
| Maximum power (Pmax) | 155 W |
| Optimum operating current (Imp) | 8.45 A |
| Optimum operating voltage (Vmp) | 19.54 V |
| Short circuit current (Isc) | 9.03 A |
| Open circuit voltage (Voc) | 23 V |
| Weight | 12 kg |
| Dimensions | 1482*674*45 mm |


Figure 1. Experimental test bench (URAER)

These three units were tested under identical conditions at the site, with each panel cleaned separately and manually over a short period, from 05/01/2025 to 19/01/2025. The cleaning methods were allocated as follows: one panel was cleaned with a water-sodium bicarbonate mixture (PV1), the second with a cloth (PV2), and the third with water only (PV3). Additionally, a battery charge controller utilizing the MPPT algorithm was employed to regulate the power output from each PV module under study. This setup ensured that the maximum power was extracted from each module and efficiently stored in the battery system.

### 2.1. Performance Analysis of the PV Modules

The performance of each PV panel included in the study was evaluated using technical indicators derived from onsite data collection. These indicators were developed based on the guidelines established by the International Energy Agency (IEA) as part of the Photovoltaic Power Systems Program, originally outlined in the IEC standard 61724 [7,8,9]. This section provides a detailed explanation of the key performance indicators utilized in this study for analyzing the efficiency and effectiveness of the PV panels.

### 2.2. Energy Output $E_{DC}$

The total energy produced, $E_{DC}$, is the sum of the power measured by the module under real outdoor conditions during the measurement sampling period (τ).

$$E_{DC} = \tau \sum_{t=1}^{N} P_{mes,I} \tag{1}$$

Where τ is the sampling time of the measurements; $P_{mes,I}$ is the maximum power measured at interval of time.

### 2.3.PV Module Efficiency

The efficiency of a photovoltaic (PV) module is the ratio of the energy produced by the module to the solar incident radiation on its overall surface. This efficiency can be expressed using the following:

$$\eta = \frac{E_{DC}}{G * S} \tag{2}$$

Where $E_{DC}$ is the output energy of the PV module, G is the global solar radiation incident on the surface of the module ($W/m^2$) and S is the total surface of the module ($m^2$).

## 3. Results and Discussion

The study presented in this paper focuses on the presentation and analysis of onsite data collected for three photovoltaic cleaning methods during the observation period. The technology under investigation involved Mono-Si modules. These modules were installed with a southward orientation and a tilt angle of 32° at the designated site.

The analysis was conducted based on specific measurements, including daily average solar radiation, daily average energy efficiency, and performance ratio. Figure 2 illustrates the daily solar radiation at the module level the period from 05/01/2025 to 19/05/2025.

The analysis of the daily solar radiation data reveals an average value of 310.38 W/m² during the observation period. The minimum solar radiation recorded was 122.45 W/m² on 12/01/2025, while the maximum value reached 361.04 W/m² on 11/01/2025, resulting in a radiation range of 238.60 W/m². This significant variability in solar radiation highlights the fluctuating environmental conditions at the site, which can have a considerable impact on the performance of photovoltaic systems. Understanding these variations is crucial for optimizing the efficiency and reliability of solar energy systems under real-world operating conditions.

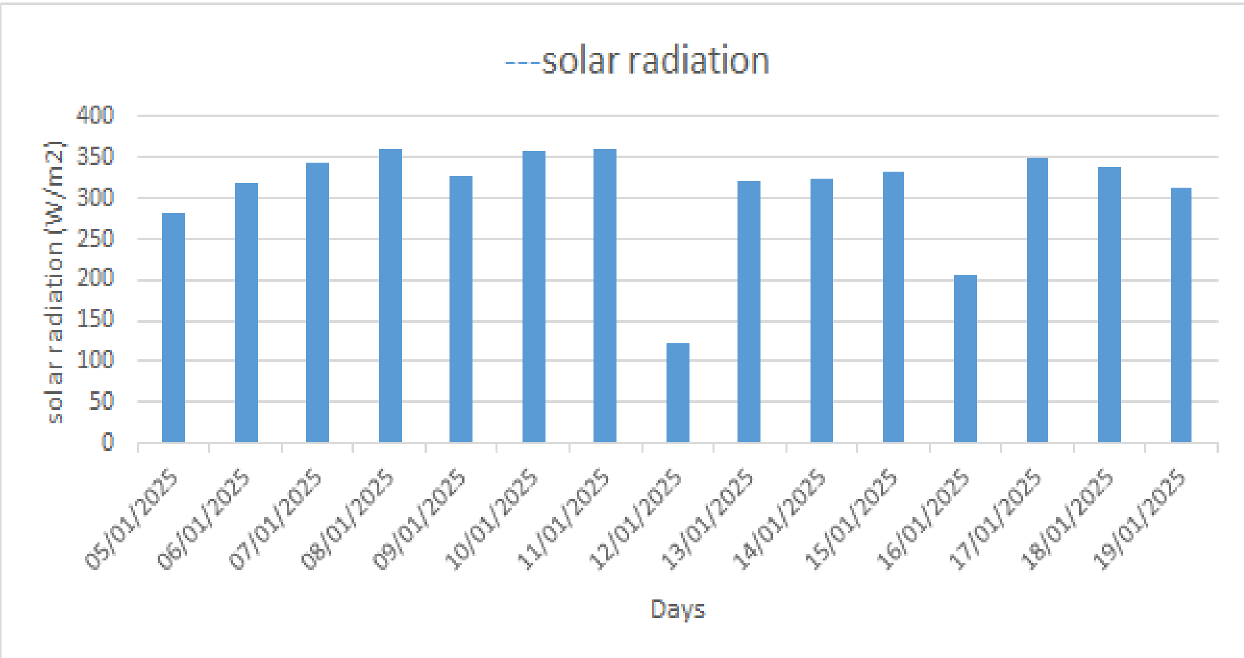


Figure 2. Daily average solar radiation in Ghardaia

Figure 3 illustrates the analysis of the performance data for the three cleaning methods. The water-sodium bicarbonate mixture (P1) proves to be the most effective, with an average performance of 114.40, a maximum of 134.3, and a minimum of 89.63.

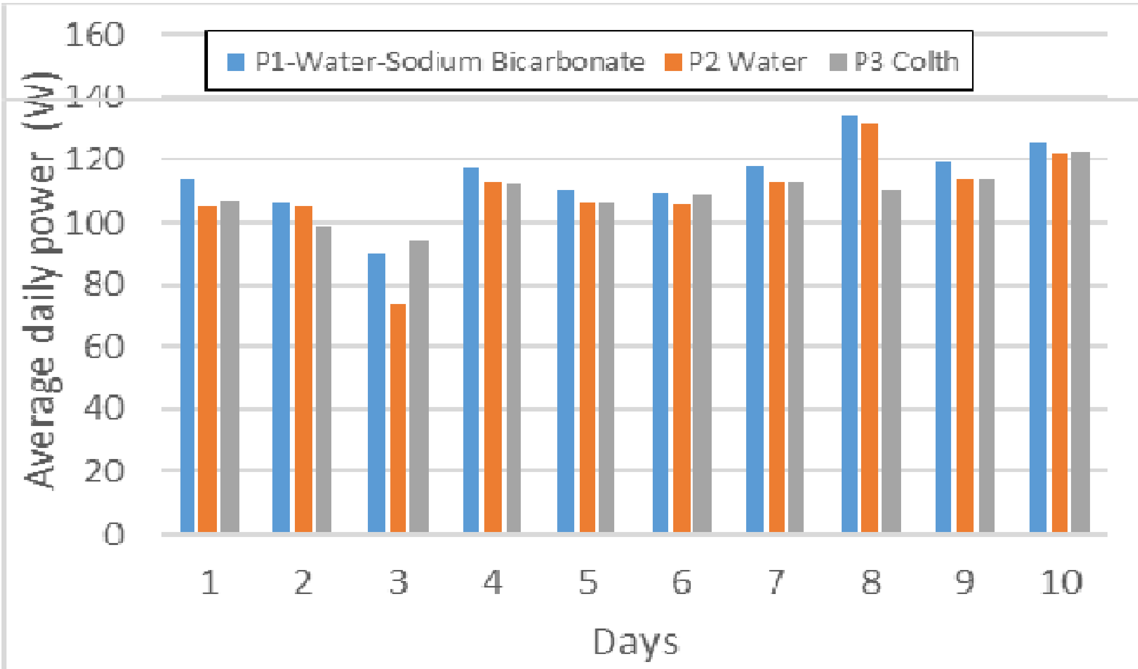


Figure 3. Comparison of daily energy outputs of three Mono-Si photovoltaic panel-cleaning technologies

In comparison, the water cleaning method (P2) demonstrates an average performance of 108.85, with a maximum of 131.4 but a lower minimum of 73.91, indicating greater variability. The cloth cleaning method (P3) achieves an average performance of 108.67, a maximum of 122.7, and a relatively stable minimum of 93.82. These findings indicate that the P1 method not only provides the highest average performance but also achieves the highest maximum values.

Meanwhile, the P3 method is noted for its consistent performance. This analysis confirms that the water-sodium bicarbonate mixture is the most effective solution for enhancing the efficiency of solar panels under the studied conditions.

Figure 4 presents a comparative analysis of the performance of photovoltaic (PV) modules based on three cleaning methods: P1 (Water-Sodium Bicarbonate), P2 (Water Cleaning), and P3 (Cloth Cleaning). The results show that P1 achieved the highest average daily output power of 114.40 W, outperforming P2 and P3, which recorded 108.85 W and 108.67 W, respectively. This highlights the superior effectiveness of the water-sodium bicarbonate mixture in maintaining panel performance under harsh environmental conditions. Similarly, in terms of efficiency,

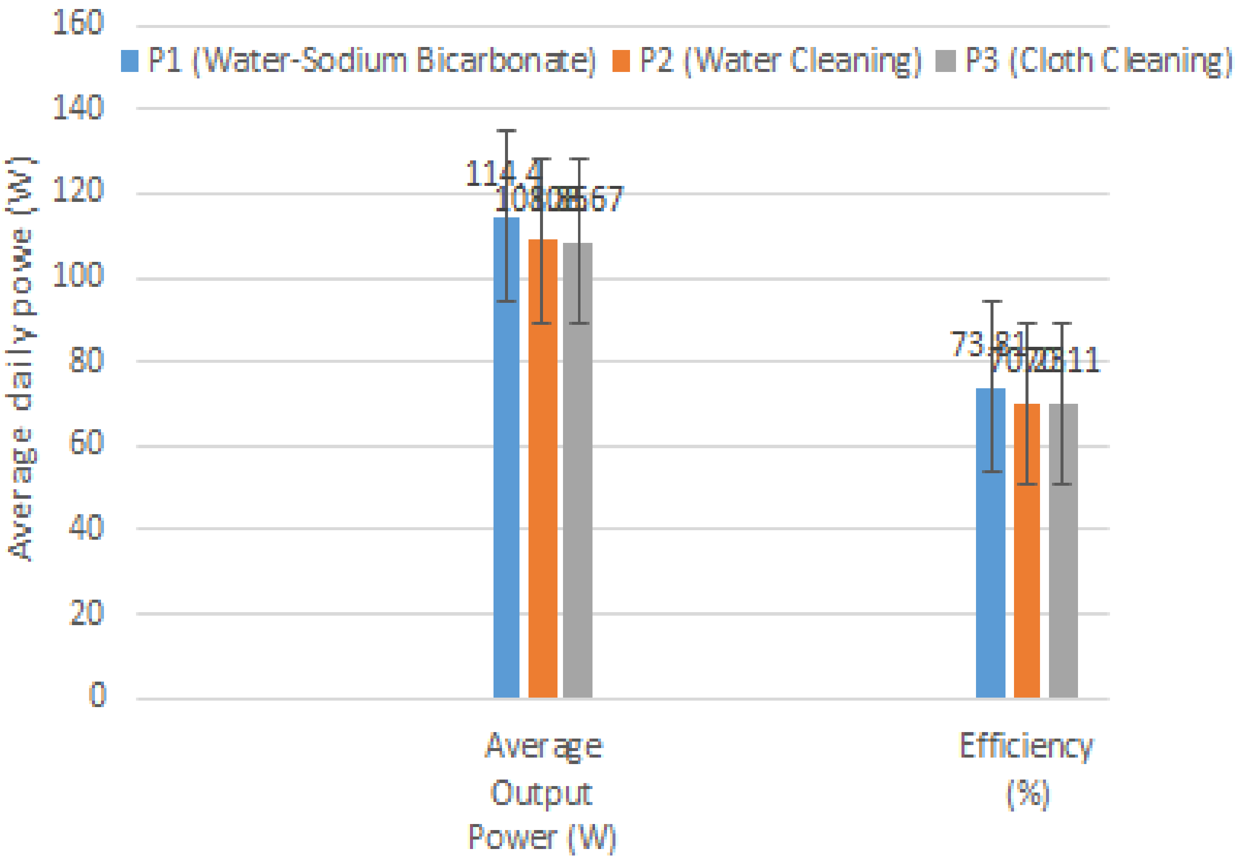


Figure 4. Comparative Analysis of Average Daily Output Power and Efficiency of PV Modules Using Different Cleaning Methods

P1 reached the highest value of 73.81%, while P2 and P3 achieved slightly lower efficiencies of 70.23% and 70.11%, respectively. The error bars indicate variability in performance, with P1 demonstrating less variability compared to P2 and P3, suggesting a more consistent cleaning outcome over the observation period. These findings confirm that the water- sodium bicarbonate mixture is the most effective cleaning method for enhancing PV module performance, particularly in desert-like environments where dust accumulation poses significant challenges.

## 4. Conclusion

This study underscores the critical role of effective cleaning methods in maintaining and enhancing the performance of photovoltaic (PV) modules, particularly in harsh desert conditions such as those in Ghardaia, Algeria. Among the three cleaning methods examined, the water-sodium bicarbonate mixture (P1) emerged as the most effective, delivering the highest average daily output power (114.40 W) and efficiency (73.81%). This method outperformed water cleaning (P2) and cloth cleaning (P3) in terms of both performance and consistency, as evidenced by the lower variability in results. The findings highlight the importance of using innovative and efficient cleaning techniques to mitigate the adverse effects of dust accumulation, thereby optimizing energy output, reducing maintenance costs, and ensuring reliable operation of solar energy systems in arid and dusty regions. These insights can contribute to the development of sustainable solutions for maximizing the performance and longevity of solar installations in challenging environments.

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