

# Optimizing Cleaning Frequency for Photovoltaic Panels: Balancing Dust Accumulation and Energy Yield in Arid Climates

Fayzullayeva Shahlo<sup>1\*</sup>, Djurayeva Shoir<sup>2</sup>, Bobojonova Madina<sup>2</sup>, Malikova Shoirao<sup>3</sup>, Xasanova Lola<sup>2</sup>, Ruzieva Nilufar<sup>4</sup>, Sattorova Maftuna<sup>4</sup>

<sup>1</sup>Tashkent University of Information Technologies named after Muhammad al-Khwarizmi, Tashkent, Uzbekistan

<sup>2</sup>Asia International University, Bukhara, Uzbekistan

<sup>3</sup>Bukhara State University, Bukhara, Uzbekistan

<sup>4</sup>Bukhara State Pedagogical Institute, Bukhara, Uzbekistan

**Abstract.** Dust deposition on photovoltaic (PV) panels poses a serious challenge in arid and desert environments, as it leads to a substantial reduction in solar energy conversion efficiency and overall system performance. The provided study is a simulation of the impact PV efficiency is exposed to various cleaning strategies within the timeframe of 150 days in Tashkent, Uzbekistan. Using four scenarios, the model was able to simulate; clean PV, unclean PV, weekly cleaned, and monthly cleaned. The findings indicate that untidy panels may end up losing as much as 30 percent of their energy production to the dust and that weekly cleaning will keep more than 93 percent of the optimum performance. Output is also better with cleaning done monthly, but this is less effective. A PID type control system also was tested where cleaning would go automatic when power loss was over 15%. This intelligent design led to an avoidance of redundant maintenance at minimal cost of performance. The simulation focuses on frequent or smart cleaning modes for dusty conditions. This led to the development of actionable insights to enhance solar energy production in areas with high dust content and therefore provide cleaner and more reliable energy sources.

## 1 Introduction

At the same time, solar photovoltaic (PV) technology plays a central role in the global transition toward clean and sustainable energy solutions [1]. Favorable climate conditions and the energy demand in solar-rich regions, such as in Central Asian countries and the Middle East, are leading to a rapid pace in PV installations. Yet again, despite the abundance of solar radiation, there is one element that will undermine the efficacy of such systems: dust accumulation on the panels' faces [2]. This is a biological occurrence and is a phenomenon more prevalent in dry and semi-dry regions, which causes a significant decline in the passage of sunlight through the protective cover glass of PV modules. Researchers have established

---

\* Corresponding author: [shahlo9735@gmail.com](mailto:shahlo9735@gmail.com)

that even after a couple of weeks or a few months, the dust may lead to the loss of energy yield of between 10 and more than 40 percent depending on the local climatic conditions and orientation of the panel [3-5].

In this regard, a variety of research studies have been dedicated to finding the optimal building cleaning frequency that could bring forth maximum energy output at the least maintenance expenses. Under-cleaning results in a severe reduction in performance, whereas the amount of cleaning that is too frequent poses risks to the labor and water consumption, especially in regions with the water shortage problem. A survey on the Dehesa region in Spain also concluded that monthly cleaning resulted in over 11 percent increase in the annual energy production, but that there was little benefit in cleaning outside of the dry seasons as rainfall was natural [6]. Contrastingly, a study in Abu Dhabi advised to implement an optimal cleaning period of 34 days considering the specific dust and energy costs [7]. Other studies in desert climates tend to indicate a general cleaning frequency of 15 to 20 days in order to ensure that no more than 5% of power is lost [8-9], although other areas of great dust density may necessitate weekly cleanings to ensure only slightly reduced efficiency values [10]. It is clear that climate and geography are defining factors when it comes to the frequency of cleaning. Panels in moist areas may also obtain natural cleaning through rain but in dry and dusty areas, soiling is faster and low level of natural cleaning occurs. This establishes the necessity of the localized approach to the cleaning, in terms of consideration of regional weather conditions, dust structure, and economic effectiveness of the systems [11-12]. The performance of PV cleaning is starting to change due to new technological innovations. Emerging solutions in automated robotic cleaners, the use of tilting, shedding and shedding of systems and the electrodynamic screen (EDS) have been illustrated as potential alternatives to the conventional manual or water-based cleaning [10, 12-13]. The technologies are meant to minimize the water consumption, labor, and maintenance time-points, which are of particular relevance in the case of extensive PV farms.

This study aims to investigate how cleaning frequency affects PV energy efficiency in dusty environments and how to create cost-effective maintenance plans. This paper contributes to the work by uniting former studies, information about the environment, and technological knowledge to facilitate the work of PV systems in problematic areas such as Uzbekistan.

## **2 Methodology**

In this section, the modelling framework is explained for the purpose of investigating the impact of accumulating dust layers on the photovoltaic solar panel's functioning and to determine the best cleaning schedule applying a control scheme based on a PID controller. The model incorporates input environmental data, electrical properties of PVs, dust attenuation effects, and feedback-regulated cleaning of the PV to compare Energy yield under field-like arid weather climate conditions as experienced in Uzbekistan.

### **2.1 System Boundary and Scope**

The project area of work will assess how dust deposition and the effects of different cleaning frequencies over a long period of time affect the operational effectiveness of photovoltaic (PV) modules. The tested system is a monocrystalline silicon PV array mounted at a fixed tilt, oriented toward the location with the highest solar exposure in Tashkent, Uzbekistan. The simulation is done on a duration of 150 days (only the dry and dusty period when accumulation of dust is more common) when the accumulation due to dust is more common than any other period.

- The performance of the PV system is analyzed under four cleaning scenarios:

- Clean PV panel (ideal baseline without dust),
- Uncleaned PV panel (no maintenance throughout),
- Weekly cleaned PV panel, and
- Monthly cleaned PV panel.

The boundaries of the model include environmental parameters such as daily solar irradiance and ambient temperature, which were approximated from historical climate data for Tashkent. Dust accumulation is modeled as a linear daily deposition rate ( $0.025 \text{ g/m}^2/\text{day}$ ), with cleaning events applied according to defined frequencies. Furthermore, the thermal impact on module efficiency is incorporated using a temperature-adjusted performance coefficient specific to crystalline silicon modules (Table.1).

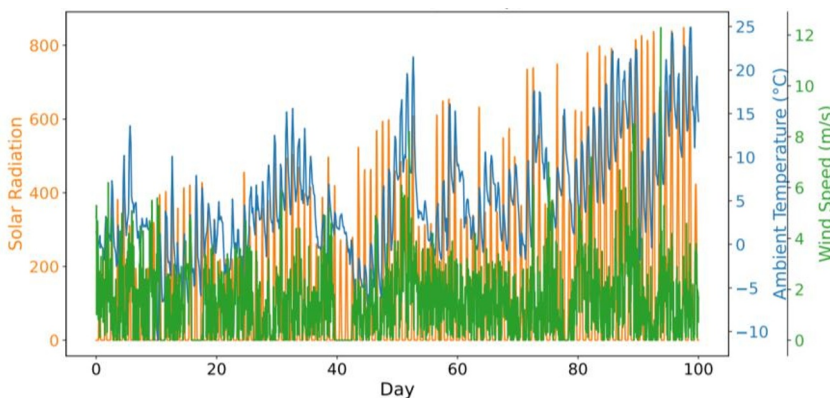
**Table 1.** Electrical and thermal specifications of the PV module under Standard Test Conditions (STC) used in the simulation study.

PV Parameter	Module Specification
Number of cells connected in series	60
Nominal power output at STC	255 W
Temperature coefficient of current ( $k_i$ )	$0.00471 \text{ A} \cdot \text{K}^{-1}$
Temperature coefficient of voltage ( $k_v$ )	$-0.122 \text{ V} \cdot \text{K}^{-1}$
Voltage at maximum power point ( $V_{mp}$ )	31.43 V
Current at maximum power point ( $I_{mp}$ )	8.2 A
Open-circuit voltage ( $V_{oc}$ )	38.09 V
Short-circuit current ( $I_{sc}$ )	8.72 A
Nominal operating cell temperature (NOCT)	$48 \pm 2 \text{ }^\circ\text{C}$

This study does not account for shading effects, humidity, rainfall events (assuming dry conditions), or inverter and system-level losses. This analysis is intended to isolate and quantify the direct consequences of dust buildup and ambient temperature on the output of photovoltaic panels. This model framework provides insight into how frequently PV modules should be cleaned to balance maintenance costs and energy yield, especially in arid or semi-arid regions with high dust exposure like Uzbekistan. The simulation results support informed decision-making for sustainable operation and maintenance (O&M) strategies in solar energy systems deployed in dust-prone climates.

## 2.2 Data From the Environment and Electrical Modelling

For two important climatic regions, representative hourly weather data (GHI, temperature, wind speed) were gathered from meteorological databases (e.g., PVGIS, Meteonorm), Fig.1.

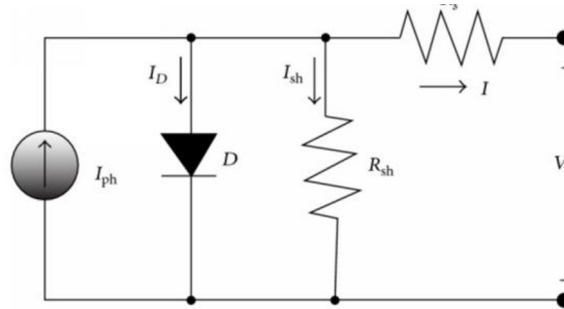


**Fig. 1.** Climate Data for Tashkent (First 100 Days).

The study employs a commercial 60-cell crystalline silicon PV module rated at 255 W under Standard Test Conditions (STC). The detailed parameters used for modeling are listed in Table 1.

where  $\alpha$  is the empirical coefficient of dust attenuation,  $\rho$  is the dust density,  $\tau$  is the actual transmittance, and  $\tau_0$  is the transmittance of clean glass.

The single-diode model is the most widely used and recognized method for assessing PV cell performance based on diode characteristics and PV cell physical properties, even though a number of techniques have been developed to investigate the output characteristics of a PV panel. Fig. 2 shows a representation of a single diode in an electrical circuit.



**Fig. 2.** The single-diode model's equivalent electrical circuit schematic.

Presented below is a numerical representation of the model with a single diode:

One of the crucial parameters for measuring the performance of the PV module is the I-V equation for the module's output, which can be obtained by applying the current Kirchhoff law to a system similar to the example in Figure 2. Using Kirchhoff's current law, the output current can first be determined as follows:

$$I = I_{ph} - I_D - \frac{V + IR_s}{R_{sh}} \quad (1)$$

where Shockley's equation can be used to determine the diode's  $I_D$ -current.;

$$I_D = I_s \left[ \exp\left(\frac{V + IR_s}{a N_s V_T}\right) - 1 \right] \quad (2)$$

where  $V_T$  is the thermal voltage,  $I_s$  is the inverse saturation current, and  $N_s$  is the number of series cells in a module.

$$V_T = \frac{kT}{q} \quad (3)$$

where  $T$  is the cell temperature in Kelvin,  $q$  represents the electron charge ( $1.602 \times 10^{-19}$  C), and the Boltzmann constant is  $k$  ( $1.38 \times 10^{-23}$  J/K). Equation (4) yields the output current when substituting equations (2) and (3) into equation (1).

$$I = I_{ph} - I_s \left[ \exp\left(\frac{V + IR_s}{a N_s V_T}\right) - 1 \right] - \frac{V + IR_s}{R_{sh}} \quad (4)$$

The module's output may be found by solving equation (4).

Dust impact can also be taken into consideration when determining output power.

The soiling loss index may be used to determine the highest possible power output of a dirty PV unit  $P_{max,0,SPV}$ . It may have shown as:

$$P_{max,0,SPV} = P_{max,g0,STC} \left( \frac{G(1+SLI)}{G_0} \right) [(1 + \Gamma(T - T_0))] \quad (5)$$

where  $gO$  refers to the total output under standard test conditions, expressed in watts (W) and SPV refers to the dirty PV panel in watts (W).  $G$  stands for total global sun irradiance.  $G_0$  represents global sun irradiance under STC conditions and a tilt angle of 30 degrees. Both variables are measured in watts per square meter, or  $W/m^2$ . The soiling loss index (SLI) is shown as a percentage. The power temperature coefficient ( $\%/^{\circ}C$ ) is shown by  $\Gamma$ . The symbols  $T$  and  $T_0$  represent the general odd and STC-based operating PV temperatures, respectively.

The Nominal Operating Cell Temperature (NOCT) model is used to calculate the actual module temperature  $T_m$  under operating conditions:

$$T_m = T_a + \left(\frac{G}{800}\right) \cdot (T_{NOCT} - 20) \quad (6)$$

Where:  $T_m$  - PV module temperature ( $^{\circ}C$ );  $T_a$  - Ambient air temperature ( $^{\circ}C$ );  $G$ - Incident solar irradiance ( $W/m^2$ );  $T_{NOCT}$  - Nominal Operating Cell Temperature ( $^{\circ}C$ ) (typically  $\sim 45^{\circ}C$ ).

### 2.3 Modelling Dust Impact and Transmittance Loss

Dust deposition is modelled as an optical transmittance reduction  $\tau$ , affecting incident solar irradiance:

$$G_{eff}(t) = G(t) \cdot \tau(t) \quad (7)$$

where:

$$\tau(t) = \tau_0 \cdot e^{-\alpha \cdot m(t)} \quad (8)$$

- $\tau_0=0.92$  is the clean panel transmittance,
- $\alpha$  is the attenuation coefficient (experimentally fitted),
- $m(t)$  is the cumulative dust mass per  $m^2$ .

Energy output and efficiency metrics are then recalculated at each time step based on updated irradiance and temperature.

### 2.4 PID-Based Cleaning Frequency Optimization

To achieve optimal control over dust accumulation and cleaning intervals, a proportional-integral-derivative (PID) controller is incorporated. The error signal will be displayed as follows:

$$e(t) = P_{max,ref} - P_{measured}(t) \quad (9)$$

The control law is:

$$u(t) = K_p \cdot e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \quad (10)$$

Where:

- $u(t)$  triggers cleaning when the error exceeds a performance threshold,
- PID gains  $K_p$ ,  $K_d$ ,  $K_i$  are tuned based on panel type and site-specific fouling rates.

This dynamic cleaning paradigm makes sure that cleaning is done on a basis where the performance degradation is beyond the tolerability levels and the cleaning produces maximum energy with minimal unnecessary maintenance.

## 2.5 Simulation and Visualization

The model is implemented in Python using NumPy and Matplotlib. The simulation produces:

- Trend of daily power outputs on each one of the four cases,
- The build-up of dust is a time-based curve,
- Useful irradiance comparison (clean and soiled),
- Bar charts of accumulative energy yield,
- Cleaning PID-cleaning efficiency relative to other uncleaned systems,
- Percentage energy loss in each case based on the comparison with the clean baseline.

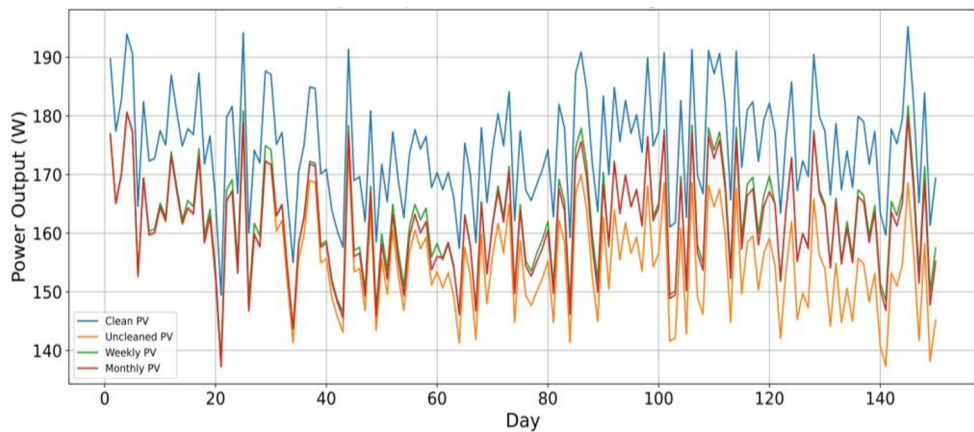
These results give quantitative information on the impact of cleaning regimes and dust deposition on PV system efficiency under arid climate, which helps inform more intelligent O&M planning when rolling out solar systems in such regions as Uzbekistan.

## 3 Simulation Results

The proposed report displays the simulation results of four PV cleaning cases, that is, Clean, Uncleaned, Weekly Cleaned, and Monthly Cleaned, during the entire operation of 150 days in a simulated arid climate environment such as the one located in Tashkent in Uzbekistan. The performance parameters would be power generation per day, total energy production, dust deposition patterns and the effective irradiance loss, and effect of cleaning control strategy based on PID.

### 3.1 Diurnal Power Generation of Alternative Cleaning Schedule

In figure 3, the distribution of power output in each of the four cleaning scenarios is demonstrated over time.

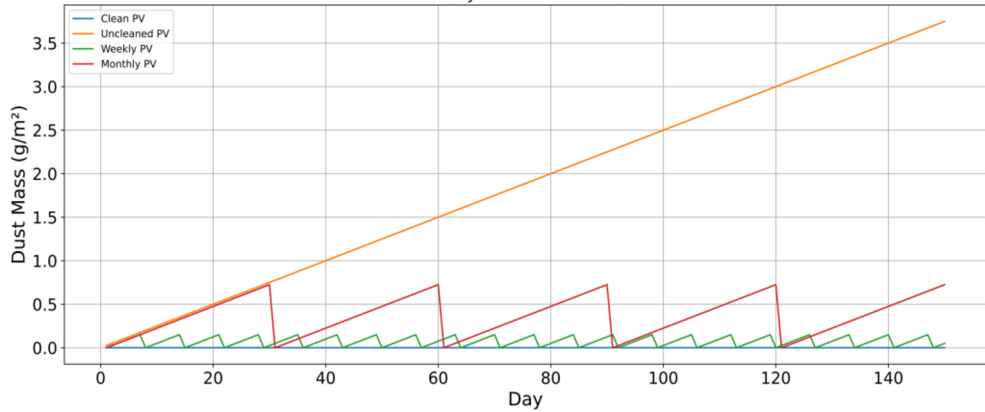


**Fig.3.** Daily PV Output Power for Different Cleaning Scenarios

Throughout the simulation, the Clean PV system keeps high output stable. Conversely, Uncleaned PV system suffers a steady decay in performance caused by linear deposit of dust. The Weekly Cleaned scheme exhibits a saw-tooth behaviour and there is the restoration of power every week. The Monthly Cleaned panel is done moderately with a longer duration of degradation time between the intervals of cleaning.

### 3.2 Dust Accumulation Dynamics

Figure 4 presents the dust mass accumulation over time.

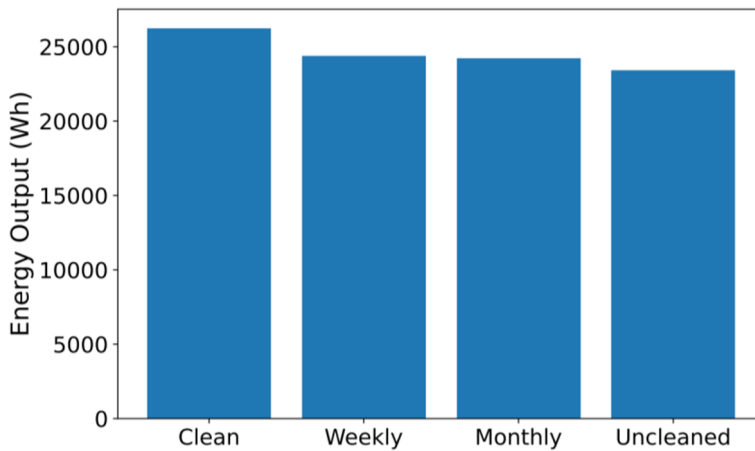


**Fig.4.** Dust Density Accumulation Over Time.

The Uncleaned panel reaches a maximum of  $3.75 \text{ g/m}^2$  after 150 days, directly correlating with optical degradation. The Weekly Cleaned and Monthly Cleaned panels reset their dust load every 7 and 30 days, respectively, maintaining much lower cumulative fouling levels. The Clean PV scenario, as expected, shows zero accumulation.

### 3.3 Cumulative Energy Yield and Loss Analysis

The total energy output over 150 days was calculated for each scenario (Figure 5).



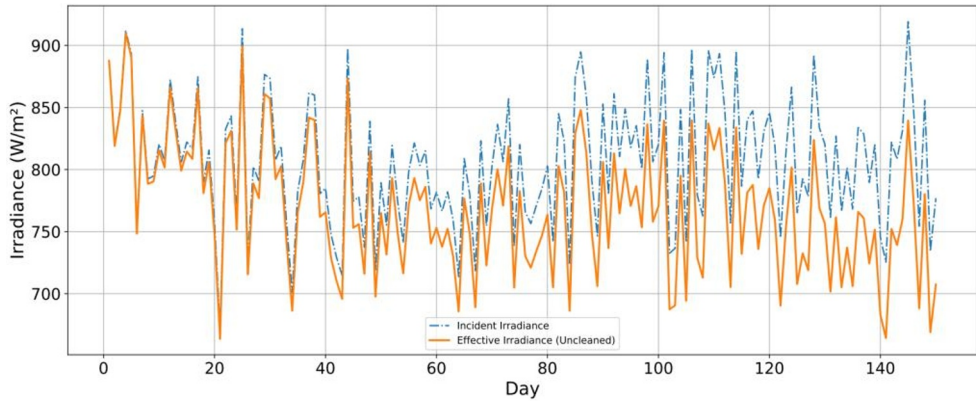
**Fig. 5.** Cumulative Energy Output Over 150 Days.

The Clean PV panel generated the highest energy yield, used as the baseline for comparison. Compared to the baseline, uncleaned PV panels lost approximately 25-30% of potential energy, monthly cleaned panels lost 13-17% of energy, while weekly cleaned panels retained over 93-95% of their energy yield.

These results confirm that regular cleaning significantly improves long-term energy capture, with weekly cleaning providing a close approximation to ideal conditions.

### 3.4 Effective Irradiance Trends

Figure 6 compares the incident irradiance with the effective irradiance reaching the PV cells in the uncleaned scenario.

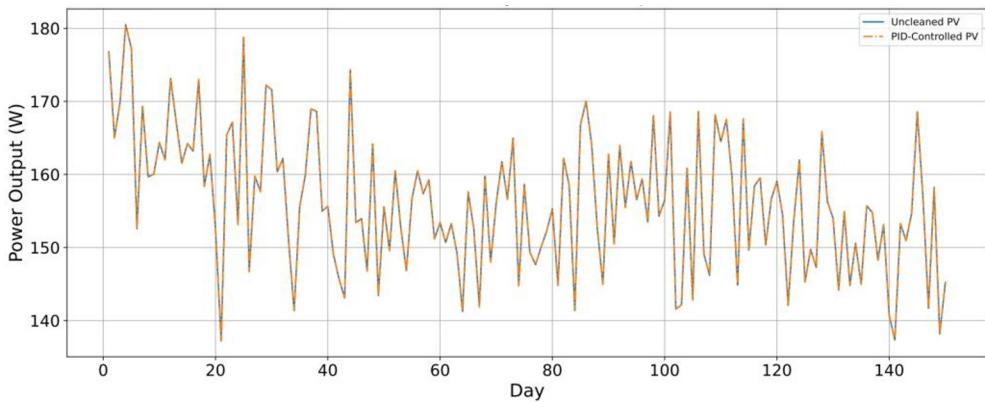


**Fig. 6.** Effective Irradiance vs Incident Over Time.

With growing dust mass, the effective irradiance decreases gradually which decreases thermal conversion and energy production. With 150 days, almost 2025% of usable irradiance of the uncleaned panel is reduced compared to a clean panel, and optical transparency is crucial.

### 3.5 PID-Based Cleaning Optimization

A basic PID type control logic was modelled, whereby, cleaning was activated when the power output decreased by more than 15% of the clean reference.



**Fig. 7.** PID-Based Cleaning vs Uncleaned PV Output.

The PID-cleaned PV panel does much better than the uncleaned panel as illustrated in figure 7 and is able to dynamically recover the output when required. The PID approach ensures that the performance and maintenance effort is minimized even though not as regular as planned weekly cleaning, it reduces unnecessary cleaning.

### 3.6 Summary of Results

The high and detrimental impact of dust on PV performance and the effectiveness of scheduled and adaptive cleaning systems are confirmed by simulation. Weekly cleaning has the optimal balance between simplicity and recovery of performance, whereas the PID strategy supports condition-based smart maintenance to maximize the energy production with minimal interventions.

## 4 Results and Discussion

This part covers the major results of the research by comparing various cleaning conditions of photovoltaic (PV) panels during dry conditions of 150 days in Tashkent, Uzbekistan. These figures and models assist in the perception of the impact of dust on the production of energy and how various cleaning practices can be used to enhance PV performance.

### 4.1 Daily Power Output (Figure 3)

The change in power output per day in four situations (Clean PV, Uncleaned PV, Weekly Cleaned PV, and Monthly Cleaned PV) are shown in figure 3. The highest amount of energy generated per day is the clean PV panel since it does not have dust. The untouched panel experiences a continuous decline in the power level, as dust accumulates and prevents the passage of sunlight. Panels cleaned weekly to maintain their output levels more consistently, with minimal reduction between cleaning cycles. Panels cleaned on a monthly basis experience longer intervals between maintenance, resulting in reduced power output for a longer period. Key-point: It is obvious that frequent cleaning is a way of regaining energy lost to the dust. The performance is maintained at a very close proximity to clean conditions due to its weekly cleaning.

### 4.2 Dust Accumulation Over Time (Figure 4)

In Figure 4, the amount of the dust on the PV surface as a result of each of the scenarios is indicated. In uncleaned scenario, dust accumulates continuously and at the end of 150 days, dust measures more than 3.5 grams per square meter. In the case of the weekly and monthly cleaning, it is set to the mass of dust which is zero at the end of every cleaning. Dust levels are maintained with low levels of cleaning every week and high levels of monthly cleaning.

Suggestion: Cleaning the panel more often will result in the surface being cleaner, and hence, will result in a better energy performance.

### 4.3 Total Energy Output and Energy Loss (Figure 5)

- In Figure 5 and the energy table, we can see the total energy produced in 150 days. The clean PV panel gives the highest result and is used as a reference. Compared to this:
- The uncleaned PV panel loses about 25–30% of its possible energy.
- The monthly cleaned panel loses around 13–17%.
- The weekly cleaned panel loses only 5–7% and is the closest to clean conditions.
- Main point: Without cleaning, a large amount of energy is lost. Even monthly cleaning helps recover most of this. Weekly cleaning gives nearly full performance.

#### 4.4 Effective Irradiance (Figure 6)

Figure 6 compares the real solar energy available (incident irradiance) with what actually reaches the panel after dust (effective irradiance). In the uncleaned case, dust makes the glass surface less transparent, so the panel gets less energy. This drop in effective irradiance becomes bigger each day and leads to less electricity generation.

**Main point:** Dust acts like a filter and reduces the sunlight that reaches the PV cells, lowering performance.

#### 4.5 Smart Cleaning Using PID Control (Figure 7)

Figure 7 demonstrates that PID-based (Proportional-Integral-Derivative) cleaning system could be employed to clean the panel only at the time of necessity. The system verifies the extent of the decrease in power output of the panel in comparison to a clean panel. When there is a drop greater than 15, it causes cleaning. Consequently, this system is superior to uncleaned panel and consumes less water and labor compared to regular cleanup plans.

Thesis statement: An intelligent cleaning system is able to allow a balance between performance and maintenance expenses. It also cleans just in time and maintains the energy output high.

#### 4.6 Overall Findings

The simulations indicate that the influence of dust on the PV performance is incredibly negative. Cleaning aids in restoring this lost energy and the more the cleaning, the better. Cleaning once a week is highly effective with monthly cleaning being conducive too. The PID system is suitable in cleaning using intelligent and condition-based cleaning in areas where there is limited water and maintenance resources.

Lesson learned: PV systems in dry and dusty areas such as Uzbekistan should be maintained or intelligently regulated in order to achieve maximum energy output and financial gain.

## Conclusion

The paper has discussed dust affects photovoltaic (PV) panels in dry climates, through a simulation model in a dry season of 150 days in Tashkent in Uzbekistan. There were four scenarios compared i.e. clean panels, uncleaned panels, weekly cleaned panels and monthly cleaned panels. The results show that dust accumulation significantly reduces the PV module's power output by blocking sunlight and increasing its surface temperature. Approximately 25-30 percent of the potential energy of the uncleaned panel was lost. Conversely, the weekly cleaning ensured that performance was kept very near in an ideal condition with only 5-7 critical losses. Good results were also achieved by monthly cleaning though with a lesser effect. Also, a smart cleaning process with a PID (Proportional Integral Derivative) control system was tested. This approach activated cleaning when the performance decreased by over 15 percent which contributed to economic saving of water and minimization of maintenance expenses without compromising energy efficiency. These results demonstrate the significance of frequent or intelligent cleaning in dusty places. In areas such as Uzbekistan, where the sun is the most important and rain is not common in cleaning, maintenance plans are crucial in the efficiency of the system. It is advised to balance the energy yield and operational cost by cleaning or PID based control every week. Such

lessons can assist solar operators, policymakers, and engineers to set up PV systems in desert-like climates, which are more efficient and sustainable.

## References

1. A.O. Ali et al., Advancements in photovoltaic technology: A comprehensive review of recent advances and future prospects, *Energy Conversion and Management*: **26**, 100952, (2025). <https://doi.org/10.1016/j.ecmx.2025.100952>.
2. Hua Y., et. al., The Impact of Climate Change on Solar Radiation and Photovoltaic Energy Yields in China. *Atmosphere*, **15**, 939, (2024). <https://doi.org/10.3390/atmos15080939>.
3. S.Z. Said et al., Dust impact on solar PV performance: A critical review of optimal cleaning techniques for yield enhancement across varied environmental conditions, *Energy Reports* **12**, 1121–1141, (2024). <https://doi.org/10.1016/j.egy.2024.06.024>.
4. L. T. Siow, J. R. Lee, E. H. Ooi, Application of graphene and graphene derivatives in cooling of photovoltaic (PV) solar panels: A review, *Renewable and Sustainable Energy Reviews*, **193**, 114288, (2024). <https://doi.org/10.1016/j.rser.2024.114288>.
5. S.R. Shajid et al, Impact of dust, humidity, and design flaws on PV performance: A review, *Energy Reports* **15**, 108926, (2026). <https://doi.org/10.1016/j.egy.2025.108926>.
6. G. Sanchez-Barroso, J. Gonzalez-Domínguez, J. García-Sanz-Calcedo et al., Markov chains estimation of the optimal periodicity for cleaning photovoltaic panels installed in the dehesa, *Renewable Energy* **179** (2021) 537-549. <https://doi.org/10.1016/j.renene.2021.07.075>.
7. Matar A.G., An H., Optimal Scheduling of PV Panel Cleaning and Policy Implications Considering Uncertain Dusty Weather Conditions in the Middle East. *Systems*, **12**, 418, (2024). <https://doi.org/10.3390/systems12100418>.
8. H. Aljaghoub et al., Solar PV cleaning techniques contribute to Sustainable Development Goals (SDGs) using Multi-criteria decision-making (MCDM): Assessment and review, *International Journal of Thermofluids* **16**, 100233, (2022). <https://doi.org/10.1016/j.ijft.2022.100233>.
9. A. Elamim et al., Performance analysis of innovative cleaning and soiling mitigation solutions in the semi-arid climate of Benguerir Morocco, *Heliyon* **9**, e16163, (2023). <https://doi.org/10.1016/j.heliyon.2023.e16163>.
10. Ali Hasan Shah et al, The influence of cleaning frequency of photovoltaic modules on power losses in the desert climate, *Sustainability*, **12**, 9750, (2020). <https://doi.org/10.3390/su12229750>.
11. M. Gandomzadeh et al, Dust mitigation methods and multi-criteria decision-making cleaning strategies for photovoltaic systems: Advances, challenges, and future directions, *Energy Strategy Reviews* **57**, 101629, (2025). <https://doi.org/10.1016/j.esr.2024.101629>.
12. Mohammad Reza Maghami, Impact of dust deposition on photovoltaic systems and mitigation strategies, *Technologies*, **14**, 15, (2026). <https://doi.org/10.3390/technologies14010015>.
13. J. Farrokhi Derakhshandeh et al., A comprehensive review of automatic cleaning systems of solar panels, *Sustainable Energy Technologies and Assessments* **47**, 101518, (2021). <https://doi.org/10.1016/j.seta.2021.101518>.