Latin American Journal of Energy Research - Lajer
periodicos.ufes.br/lajer

Latin American Journal of Energy Research – Lajer (2025) v. 12, n. 2, p. 42–49
https://doi.org/10.21712/lajer.2025.v12.n2.p42-49

Assessment of dirt impacts on photovoltaic modules in electricity generation

Avaliação dos impactos da sujidade em módulos fotovoltaicos na geração de energia elétrica

Diogo Franchi[1,*], Enzo Cirolini Cervo[1], Maicon Miotto[1], Frank Gonzatti[1], Felix Alberto Farret[1]

[1] Centro de Excelência em Energia e Sistemas de Potência – CEESP da Universidade Federal de Santa Maria – UFSM, Brasil,
*Autor para correspondência, E-mail: diogofranchi@gmail.com

Received: 16 May 2025 | Accepted: 25 July 2025 | Published online: 03 August 2025

Abstract: This article analyzes the impact on the performance of photovoltaic (PV) modules due to the accumulation of dirt on their surface under different cleaning maintenance routines. PV modules were analyzed with varying maintenance periods, ranging from more than 4 years without cleaning to quarterly and semiannual routines. The results showed a 3.29% difference in energy generation between the modules subjected to the highest and lowest cleaning frequencies. Furthermore, it was observed that natural cleaning methods, such as precipitation, were effective only in removing light particles, such as dust, but not in removing more adherent dirt on the module surface. In subsequent experiments, it was found that modules without maintenance for up to 21 days showed insignificant generation losses, while significant losses began to occur after 45 days, and stabilizing after about 5 months.
Keywords: photovoltaics; dirt; maintenance; cleaning.

Resumo: *Este artigo analisa o impacto no desempenho de módulos fotovoltaicos (FV) devido ao acúmulo de sujeira em sua superfície sob diferentes rotinas de manutenção de limpeza. Foram analisados módulos FV com distintos períodos de manutenção, variando de mais de 4 anos sem limpeza até rotinas trimestrais e semestrais. Os resultados mostraram uma diferença de 3,29% na geração de energia entre os módulos submetidos às maiores e menores frequências de limpeza. Além disso, observou-se que métodos de limpeza natural, como a precipitação, foram eficazes apenas na remoção de partículas leves, como poeira, mas não na remoção de sujeiras mais aderentes à superfície dos módulos. Em experimentos subsequentes, verificou-se que módulos sem manutenção por até 21 dias apresentaram perdas de geração insignificantes, enquanto perdas significativas começaram a ocorrer após 45 dias, estabilizando-se após aproximadamente 5 meses.*
Palavras-chave: fotovoltaica; sujidades; manutenção; limpeza.

1 Introduction

The accelerated growth in global demand for electrical energy is a reflection of the constant search for technological advances that make people's daily lives easier. However, the predominant way of meeting this demand still raises concerns, both due to the dependence on non-renewable sources and the significant environmental impacts associated with conventional methods of energy generation. PV energy represents a strategic alternative in the energy context, providing a source of renewable electricity with low environmental impact.

According to IEA (2019) projections, PV electrical energy generation could reach around 3,268 TWh by 2030, compared to historical generation of close to 1,281 TWh in 2022 (IRENA, 2023), with an average annual growth of 16% in global installed capacity. Furthermore, it is estimated that by the year 2030 around 100 million families will depend on PV energy (IEA, 2022). According to IRENA (2023), around 298 billion dollars were invested globally in PV generation in 2022, representing 60% of global investments in renewable energy.

Recent advances and incentives for the adoption of PV systems in residential, industrial and commercial installations have driven the mobilization of institutions focused on production and research in this

area. This movement has promoted the development of both equipment and materials related, directly or indirectly, to PV technology.

Although investments in materials science, technologies and incentives to expand the use of this source of renewable electrical energy generation are fundamental, it is also crucial to optimize maintenance routines to ensure the efficiency of the technology. This is because the generation of electrical current by PV modules depends directly on solar irradiation and any obstacles, such as clouds and dirt on the surface of the modules, significantly impact the generation performance. Therefore, understanding the influence of dirt on PV modules and how dirt accumulation can affect their energy conversion performance is essential to maximizing the benefits of this renewable source.

In this article, the impact of dirt and routine cleaning maintenance on the production of electrical energy in PV plants is analyzed. In Section II, a review of the impact of lack of maintenance on the efficiency of PV modules is addressed. Section III characterizes the test environment, the Photovoltaic Experimental Center – PVEC, and Section IV details the methodology of the experiments. In Section V, the results are explored, relating the maintenance interval of the PV modules with the efficiencies obtained. Finally, in Section VI, the conclusion of the article is presented.

2 Dirt on photovoltaic plates

The costs involved in cleaning PV modules can be high depending on the climatic conditions of the region and even the surrounding environment, such as industries, highways, trees, dust, among others. To reduce maintenance costs and generation losses due to dirt, it is suggested to install modules with an inclination angle greater than 10 degrees (Jacobson and Jadhav, 2018; Oliveira and Malagón, 2018).

According to Júnior et al. (2018), the lack of an adequate maintenance routine in PV modules can cause major losses in performance, reaching an average reduction of up to 20% due to the accumulation of dirt in their experimental tests. However, the authors emphasize that there is no need for maintenance at intervals of less than 15 days, especially during rainy periods, as in the fortnightly period they observed a reduction of only 2% in generation.

Sulaiman et al. (2014), analyzed the effect that various particles have on the performance of a PV module, and their conclusions indicate that opaque particles are those that most affect performance. Sand, talc and dust significantly affect generation, but their removal often occurs naturally through rain. Moss, responsible for the greatest reduction in generation, up to 86%, requires an active maintenance to completely eliminate it. Finally, rain droplets interfere somewhat with the performance of the PV module.

Guo et al. (2015), noticed a reduction in electrical energy generation between 10 and 20% per month due to the deposition of dust on the module, located in Qatar. In the experimental tests carried out by these authors, it was found that the set of modules with low cleaning frequency present a significant loss in the index cleaning, of up to 50%, resulting in a significant loss in generation. Furthermore, as much of the dirt is made up of local dust and not moss, it was found that the rain was sufficient to restore the index cleaning of the modules.

Fatima et al. (2024), concluded that around 25% of energy losses occur if adequate cleaning intervals are not scheduled. Furthermore, they found that energy losses were reduced to 7% when PV modules were manually cleaned biweekly with fresh water, which is the most viable interval in terms of balancing cleaning cost and energy wasted due to dirt.

3 Photovoltaic experimental center

The experiments discussed in this paper were carried out at the PVEC, Figure 1, located in Santa Maria/RS – Brazil, −29.724041° latitude and −53.710812° longitude. Each PVEC PV module, with 255 watts of peak power, uses a microinverter to track the maximum operating power point and inject energy into the distribution grid. To acquire the real-time voltage and current levels of each PV module, devices composed mainly of an INA260 digital integrated circuit were developed. These devices were calibrated by a Fluke 189 with maximum errors of 0.04% and 0.52% for voltage and current values, respectively (Fluke, 2000). The average error module of these devices is 0.06% and 0.19% for current and voltage measurements, in that order (Rodrigues et al., 2018).

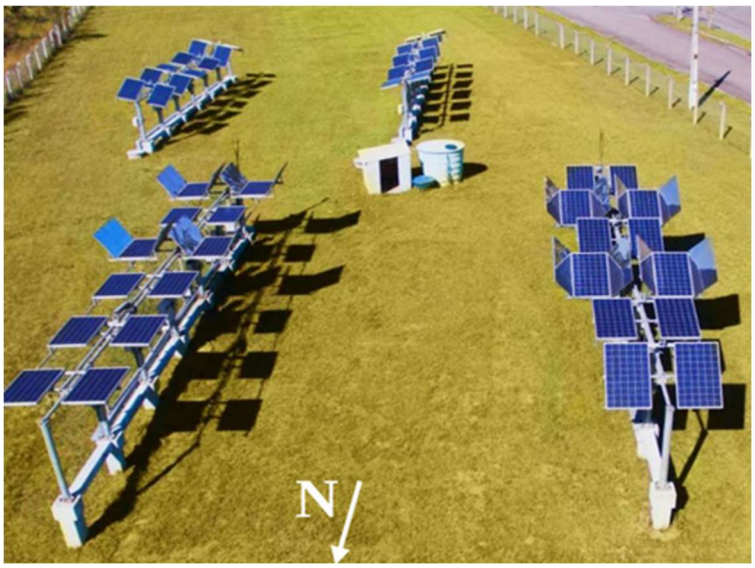

Figure 1. Photovoltaic Experimental Center. Font: Franchi et al., 2022.

4 Methodology

PVEC is located next to a street with low vehicle circulation, close to the urban area and far from the industrial area. There are no large sandy terrains or significant sources of dust particles nearby. However, the presence of a brickworks nearby can contribute to suspended particles. Based on these conditions, the influences of dirt on the energy generation of PV modules over time were analyzed, as well as the effects of partial restoration of performance due to natural precipitation (natural cleaning). In active cleaning maintenance routines, pressurized water and friction with rotating brooms with soft bristles were used.

In tests carried out with PVEC, the generation of electrical energy using PV modules was compared under the same conditions, only varying their cleaning routines. To achieve this, the study is divided into two main stages.

The first stage takes place over a semester and compares the influence of dirt on generation in a PV module that has not had cleaning routines for at least 4 years with two other modules: one with cleaning maintenance every 3 months and the other every 6 months.

In the second stage, the performance of PV modules with different cleaning routines was compared. The performance of both modules was analyzed from the moment one of them is subjected to active cleaning maintenance and the other is not, both being exposed to the same environmental dirt for the same predefined period of 7, 14, 21, 45, 110 (3.5 months), 155 (5 months), and 1460 days (4 years).

5 Results and discussions

At the beginning of the experiment, the PV modules with semi-annual and quarterly maintenance routines were subjected to active cleaning in the same period. The first stage of dirt analysis in PV modules aims to evaluate the generation of electrical energy under cleaning routines spaced over long periods, resulting in the amounts shown in Figure 2. It was found that, over six months, the average difference in electrical energy generation between the PV module with quarterly active cleaning and another that had not undergone active cleaning for at least four years was 3.29%, with a maximum daily rate of 13.42%.

Figure 3 shows the percentage of daily electrical energy generation in this first stage of the experiment. Due to the change in slope in the polynomial curve, it can be seen that the quarterly cleaning maintenance (in green) restores its generation on September 28th. Furthermore, it is noticeable that the generation of the modules without maintenance for 6 months and for at least 4 years tend to be similar by the end of the experiment. Also, the performance of PV modules exposed to a lack of cleaning routines for a period much longer than six months approaches that of the semi-annual cleaning modules in situations similar to those of PVEC.

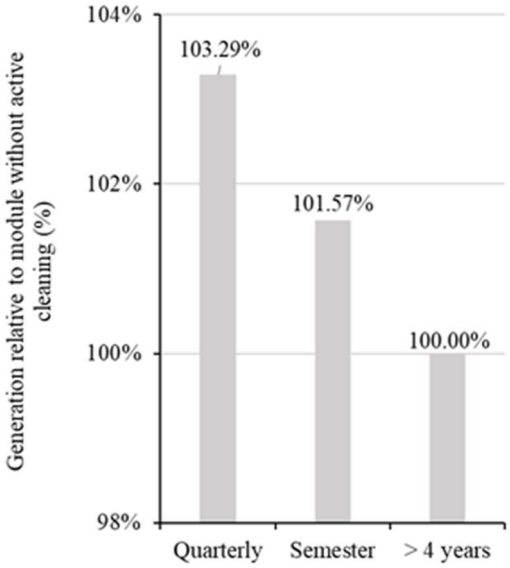

Figure 2. Percentage performance relative to the module without active cleaning.

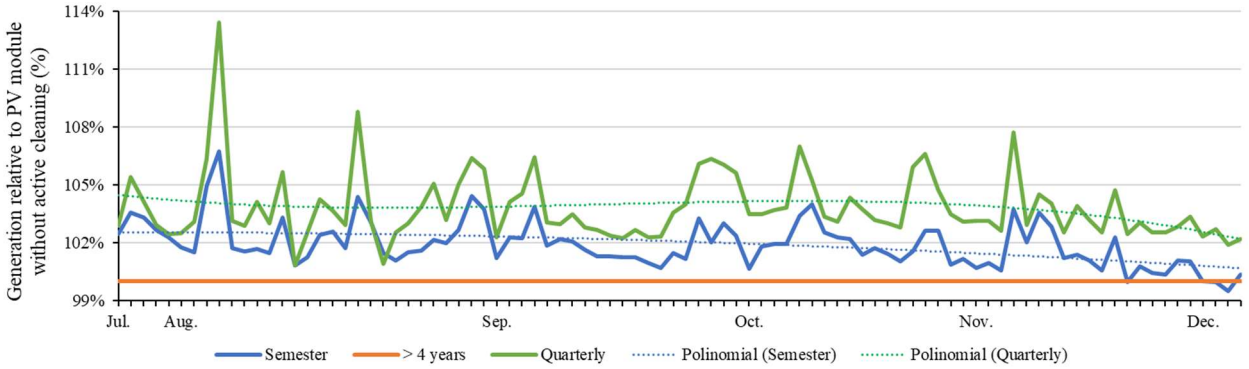

Figure 3. Percentage of daily generation relative to the module without cleaning for at least 4 years.

It is noteworthy that the percentage generation peaks in Figure 3 occur on rainy or cloudy days. In Figure 4, samples from cloudy or rainy days were removed, eliminating performance peaks. These results indicate that the precipitation used as natural maintenance of the modules does not require a complete restoration of generation in this location, as the percentage of generation between the modules is approximately the same in the period that succeeds and precedes the precipitation.

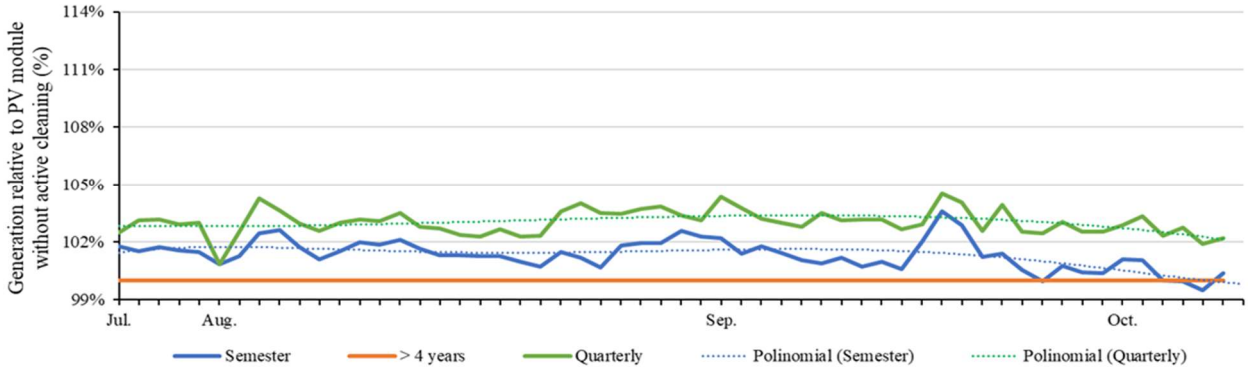

Figure 4. Percentage of daily generation relative to the module without cleaning for at least 4 years and without cloudy days.

If precipitation completely removed the dirt from the modules, in this location, the percentage generation curves would frequently intersect. Furthermore, it is understood that precipitation only removes a layer of surface and recently deposited particles from all modules, causing no impact on long-term dirt. In the location and conditions of the PVEC, precipitation does not perform as well as it could in areas that have a greater quantity of light, non-adherent particles.

Visually, it was found that non-adherent particles are removed from all modules, such as dust, but there is no removal of particles that adhere strongly to the PV modules over the days, which provide an opaque

tone and matte appearance. In active cleaning routines, the presence of particles very adherent to the PV modules is confirmed, as the use of pressurized water alone is not enough to remove all dirt, requiring repeated rubbing with bristles associated with pressurized water across the entire surface of the PV module.

Using a portable digital microscope, two cells of a PV module were recorded under different dirty conditions: one recently cleaned and the other not cleaned for 9 months, Figure 5. It was observed that, after cleaning one of the PV cells, some stains related to the most significant dirt still remained.

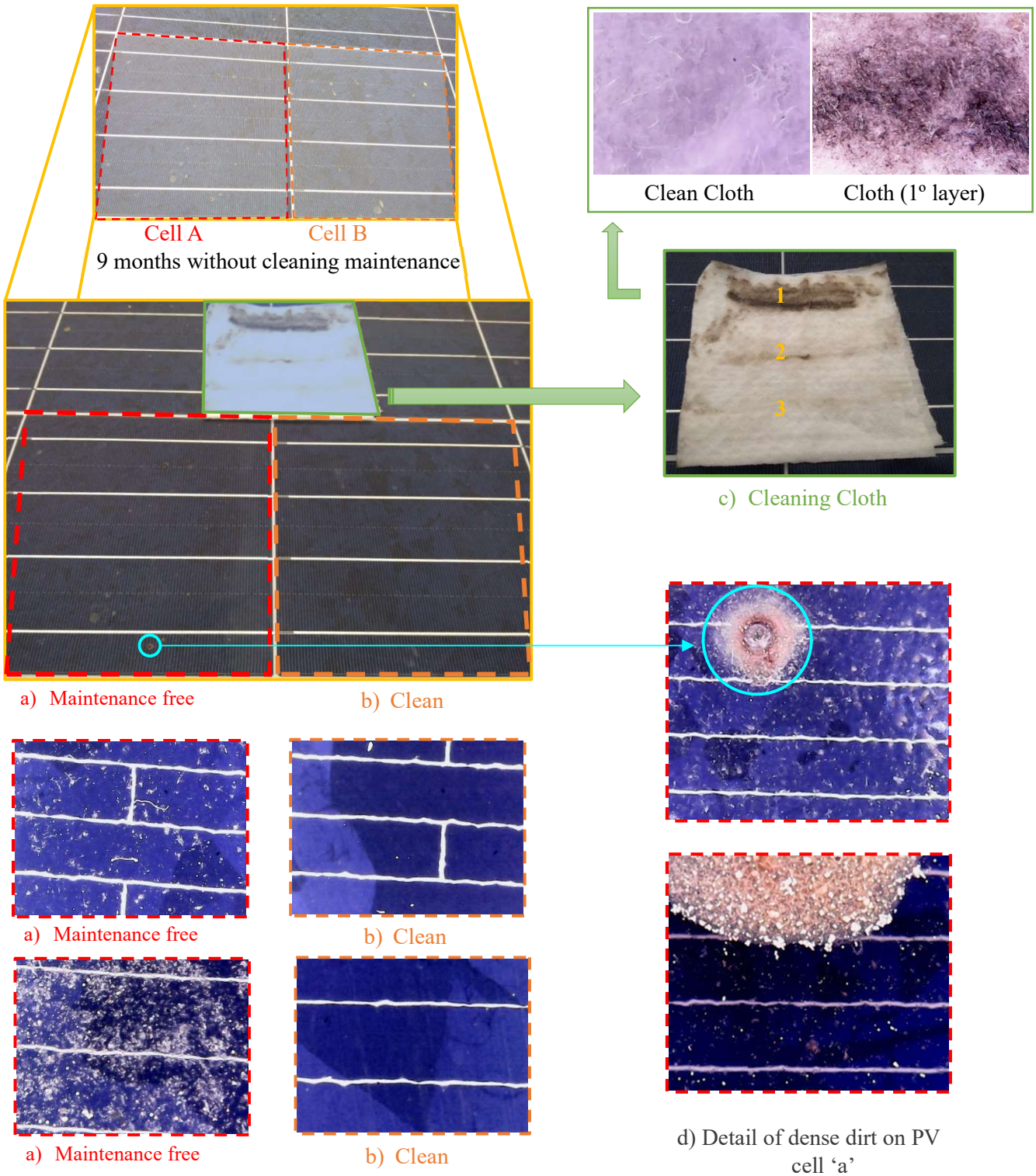

Figure 5. Comparison between cells with and without cleaning maintenance.

Therefore, to study a typical cell performance, a light-colored fabric composed of cellulose and polypropylene was used. After the cell cleaning procedure, three main layers of dirt were identified from three

consecutive rubs until the fabric no longer adhered to particles visible to the naked eye. Visually, the presence of dirt composed not only of dust, but also of dark particles that could be derived from pottery or vehicle smoke was noted. The images recorded by the microscope on the tissue before and after the cleaning procedure elucidated the dirt present in the darkened cell.

The recordings of the analyzed PVs cells with the microscope clearly illustrate the difference between their surfaces with and without the cleaning procedure. It is noticeable how much dirt fills the surface of the PV module without proper cleaning maintenance; however, it is not possible to identify the types of dirt present with this portable microscope. Furthermore, Figure 5 presents images of dirt with the highest densities recorded by the microscope on the PV cells, highlighting the degree of opacity caused by the accumulation of particles.

In the second stage of this research, the performance of PV modules under different active cleaning routines is compared. One of the modules is cleaned and exposed to the elements for a pre-defined period of time; the other PV module undergoes active cleaning after this period has elapsed, and then data collection from these modules begins for the same period.

Table 1 presents the performance values of the PV modules according to the period of time each one was without active cleaning maintenance. It should be noted that the performance percentages for cloudy days are not used, as their values are discontinuous with the others, as shown in Figure 3 and Figure 4.

Table 1. Amounts of performance of PVs modules according to the period of time without cleaning maintenance.

Maintenance-free days	Generation relative to clean PV module (100%)	Loss of performance
7	100,43%	0,43%
15	99,67%	-0,33%
21	99,91%	-0,09%
45 (1,5 months)	98,84%	-1,16%
110 (3,5 months)	97,86%	-2,14%
155 (5 months)	97,24%	-2,76%
> 4 years	97,23%	-2,77%

Throughout the operational observations of PV modules, it is noticeable that those without active maintenance for up to 21 days show virtually no significant generation losses due to dirt. On the other hand, after 45 days, performance starts to be significant. Performance appears to stabilize around 5 months without maintenance, when its performance approaches that of those modules for more than 4 years without active maintenance.

Figure 6 records the performance of modules with variable active cleaning maintenance in relation to another module that does not undergo maintenance in the analyzed period of six months. It is noticed that the average performance values for each period increase with each cleaning maintenance in relation to the module without maintenance for six months. Furthermore, at the end of the period of six months, the average increase in performance compared to the maintenance-free module is 2.89%, similar to the other results presented.

The relatively small performance losses of modules exposed for long periods without active maintenance apply to those subjected to conditions similar to the PVEC site. Under other conditions, the influence of dirt on the performance of PV modules can be much greater, as seen in Section II.

6 Conclusion

In this article, the effects of dirt at the PVEC installation site on the performance of PV modules subject to different cleaning maintenance routines is evaluated. When comparing a PV module that was not undergone to cleaning maintenance for more than 4 years with others that underwent quarterly and semi-annual cleaning routines, a difference of 3.23% in electrical energy generation was found between the extremes. Furthermore, it was found that the module that has not been cleaned for six months tends to reach a power level similar to that of the module that has been exposed to the elements for more than 4 years without any active maintenance. It was also noticed that natural cleaning by precipitation did not remove dirt with greater adhesion to the surface of the modules, being effective only for light particles, such as dust.

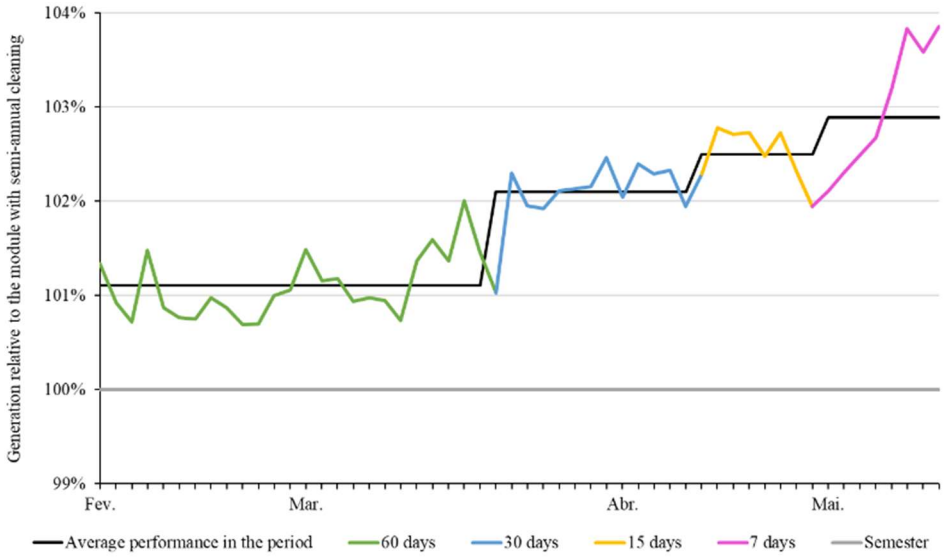

Figure 6. Percentage performance of PV modules with variable active maintenance periods in relation to the module without maintenance for a period of 6 months.

In the second phase of this research, the PV modules were exposed to different periods without maintenance and it was found that those without active maintenance for up to 21 days practically did not show significant generation losses due to dirt. On the other hand, after 45 days the performance became significant, around 1% lower. Performance appears to stabilize after 5 months without maintenance at a level close to 3% reduction, since its power has approached that of the module for more than 4 years without active maintenance.

The development and experimental results of the research in this article contribute technically to the field of study that aims to enhance the performance of PV modules. Furthermore, they also help in decision-making in the routine maintenance of dirt that affects PV modules.

Acknowledgment

This study was financed in part by the Coordination for the Improvement of Higher Education Personnel – Brazil (CAPES/PROEX) – Finance Code 001. We also thank CTISM/UFSM for the financial support and FINEP under Project reference nº. 2307/24.

References

Fatima, K, Minai, AF, Malik, H and Márquez, FPG (2024) 'Experimental analysis of dust composition impact on photovoltaic panel performance: A case study', *Electrical Engineering Department, Lucknow, India*. https://doi.org/10.1016/j.solener.2023.112206

Fluke (2000) *Model 187: 189 True RMS Multimeter*.

Franchi, D, Gonzatti, F, Miotto, M, Da Silva, EI, Lenz, JM and Farret, FA (2022) 'An experimental study on the angular step of one-axis PV trackers and its impact on energy harvesting', *Journal of Control, Automation and Electrical Systems*, 33(6), pp. 1739–1746. https://doi.org/10.1007/s40313-022-00936-9

Guo, B, Javed, W, Figgis, B and Mirza, T (2015) 'Effect of dust and weather conditions on photovoltaic performance in Doha, Qatar', *First Workshop on Smart Grid and Renewable Energy (SGRE)*. https://doi.org/10.1109/SGRE.2015.7208718

IEA (2019) *Solar*. Available at: https://www.iea.org/fuels-and-technologies/solar (accessed 6 February 2022).

IEA (2022) *Approximately 100 million households rely on rooftop solar PV by 2030*. Available at: https://www.iea.org/reports/approximately-100-million-households-rely-on-rooftop-solar-pv-by-2030 (accessed 18 December 2024).

IRENA (2023) *Solar Energy Data*. Available at: https://www.irena.org/Energy-Transition/Technology/Solar-energy (accessed 17 December 2024).

Jacobson, MZ and Jadhav, V (2018) 'World estimates of PV optimal tilt angles and ratios of sunlight incident upon tilted and tracked PV panels relative to horizontal panels', *Solar Energy*, vol. 169, pp. 55–66. https://doi.org/10.1016/j.solener.2018.04.030

Júnior, JGS, Cruz, SR and Amaral, LS (2018) 'Impact of dirt on system performance', *VII Congresso Brasileiro de Energia Solar - CBENS 2018*, Brasil. https://doi.org/10.59627/cbens.2018.123

Oliveira, FTV and Malagón, LAG (2018) 'Optimization of the tilt angle and orientation of solar panels for the city of Petrolina', *VII Congresso Brasileiro de Energia Solar - CBENS 2018*, Brasil. https://doi.org/10.59627/cbens.2018.717

Rodrigues, CM, Da Silva, EI, Franchi, D, Miotto, M, Gonzatti, F and Farret, FA (2018) 'Design and implementation of a monitoring system for electrical and thermal quantities in photovoltaic modules', *Proceedings IX Simpósio Brasileiro de Sistemas Elétricos*. https://doi.org/10.20906/sbse.v2i1.2975

Sulaiman, SA, Singh, AK, Mokhtar, MMM and Bou-Rabee, MA (2014) 'Influence of dirt accumulation on performance of PV panels', *Energy Procedia*, vol. 50, pp. 50–56. https://doi.org/10.1016/j.egypro.2014.06.006