# EXPECTATIONS VS. REALITY: A COMPREHENSIVE ANALYSIS OF UNDERPERFORMANCE IN BRAZILIAN UTILITY-SCALE SOLAR PLANTS


## Summary

This study evaluates the performance of 197 utility-scale photovoltaic (PV) plants (6.8 GW) in Brazil during 2023, comparing projected capacity factors with actual measurements. Results reveal that 81% of plants failed to meet generation expectations promised in their projects. The work analyzes the main causes of this widespread underperformance. Comparisons with international studies indicate this is a systemic problem in the global PV industry, highlighting the need to revise projection methods and performance evaluation of PV plants in the Brazilian context.


*Keywords: PV Performance, PV energy modeling, constrained-off*

## 1. Introduction

In Brazil, PV generation has already reached a total installed capacity of 55 GW, with approximately 17 GW coming from utility-scale centralized generation plants and the remaining 38 GW from distributed generation systems (ABSOLAR, 2025). All these centralized generation projects have public data associated with their generation permits (ANEEL, 2023) and projected capacity factors (CCEE, 2024; Epowerbay, 2024), enabling a comparative analysis between projected and actual performance.

Various environmental factors can affect PV system performance. Some factors are beyond human control, such as solar irradiance profiles and PV module temperatures. Other characteristics - such as shading, unavailability, and soiling - relate to both electrical performance and O&M (Operation and Maintenance) activities (Nascimento et al., 2020). PV system performance has been subject to increasing scrutiny as the technology expands globally. Recent studies have revealed a concerning trend: many photovoltaic plants, both in Brazil and elsewhere, are performing below initial projections (Bendaas et al., 2023; Dahmoun et al., 2021; kWh Analytics, 2022; Prilliman et al., 2024; Shiva Kumar and Sudhakar, 2015; Walker et al., 2020).

This discrepancy between projected and actual performance can be attributed to multiple factors. Climate variability is significant, as local weather conditions frequently diverge from historical data used in initial projections. Additionally, PV module degradation rates tend to be underestimated in initial designs (Deline et al., 2024). Operational factors such as shading, soiling, and ohmic losses can be more impactful than predicted, while unavailability due to technical failures and unscheduled maintenance can result in longer downtime than estimated (Rasmussen, 2024).

With increasing solar penetration in Brazil's energy matrix, the challenge of controlling PV generation to maintain grid stability and reliability has emerged. In this context, the concept of "constrained-off"- often used interchangeably with "curtailment" (Perez et al., 2023) - has gained prominence. Constrained-off refers to energy production reduction from centralized PV plants due to external commands from the National System Operator (ONS). These power reductions have been heavily criticized in Brazil and identified as a key factor in PV projects failing to meet their physical guarantees (Fucuchima, 2023). Given this scenario, a critical review of projection methods and performance evaluation for PV plants is clearly necessary, especially in the Brazilian context.

## 2. Results and Discussions

This study aimed to evaluate the performance of 197 centralized PV projects in Brazil, totaling approximately 6.8 GW of installed capacity. The analysis compared operational results obtained during 2023 with original expectations declared by developers when registering projects with ANEEL, known as generation permits. A fundamental issue in evaluating PV plant performance is solar resource variability. Original projects are designed considering average solar irradiation based on historical series. However, the solar resource actually available in a given year can significantly diverge from these historical averages, directly affecting plant generation expectations.

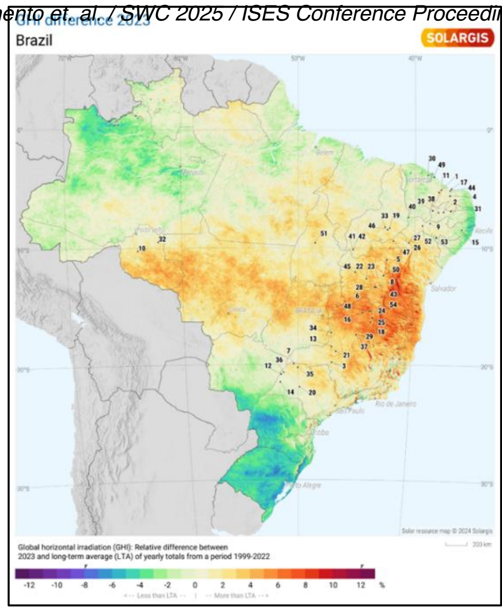


**Fig. 1: Differences between satellite-measured irradiation values in 2023 and long-term average.**

Fig. 1 presents a mapping of solar irradiation variation in Brazil during 2023 compared to the historical long-term average. On the map, the 197 plants analyzed are grouped into 51 PV complexes identified in the image. Orange and red points indicate regions where solar irradiation in 2023 was above the historical average, while green and blue points represent regions where irradiation was below the historical average.

Another relevant factor affecting plant performance is constrained-off, which occurs when the National System Operator (ONS) orders plants to reduce their power output. For 2023, these mandatory reductions resulted in an average energy loss of 5% across the analyzed projects.

Fig. 2 presents the comparison between projected capacity factors (permit) and those actually measured for the 197 PV plants analyzed during 2023. This analysis already incorporates corrections associated with both solar resource variability and constrained-off losses, allowing a more accurate assessment of the plants' intrinsic performance.

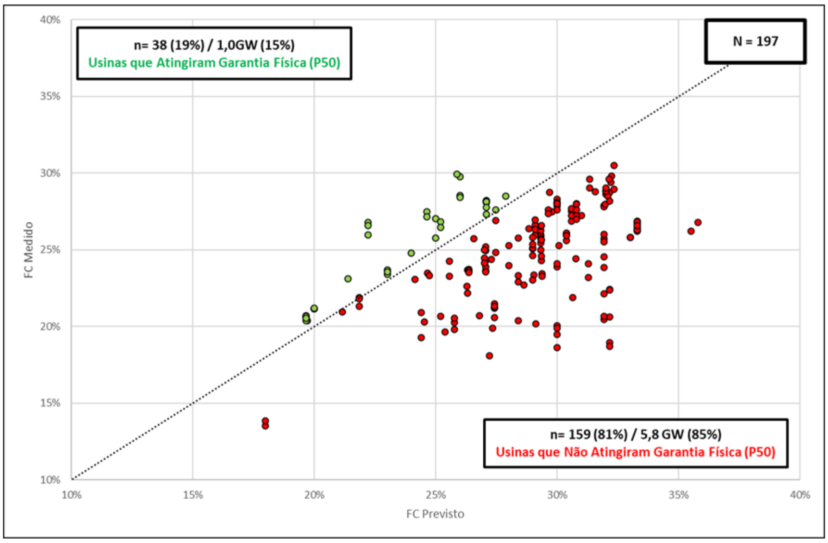


**Fig. 2: Projected and measured capacity factors of 197 utility scale PV plants for the year 2023.**

The results reveal a concerning scenario: 81% of the PV sites (representing 85% of installed capacity) did not meet generation expectations promised in their original projects, even after the mentioned corrections. Approximately 50% of plants show an energy deficit greater than 10% compared to original projections.

This scenario of widespread underperformance is not exclusive to Brazil. Studies conducted in the United States with utility-scale plants (totaling 9 GW) demonstrated that, for 2022, more than 85% of projects did not meet energy production expectations (kWh Analytics, 2022), evidencing a systemic problem in the global photovoltaic industry. The methodology adopted in this study therefore allows isolating external factors (solar resource variability and constrained-off) from possible intrinsic project deficiencies, offering a clearer view of the causes of widespread underperformance observed in Brazilian PV plants. The complete study will explore the root causes of these discrepancies and provide comprehensive analysis of the loss factors currently applied in Brazilian solar energy projects.

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