

EXPERIMENTAL ASSESSMENT OF SOILING LOSSES IN AGRIVOLTAIC SYSTEMS: INSIGHTS FROM FIELD DATA IN DENMARK AND SPAIN

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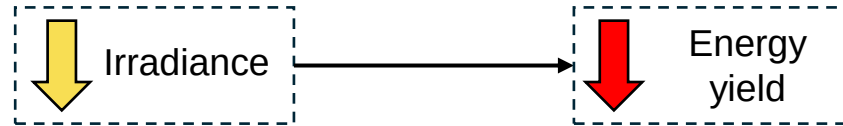


BACKGROUND

Background

Soiling

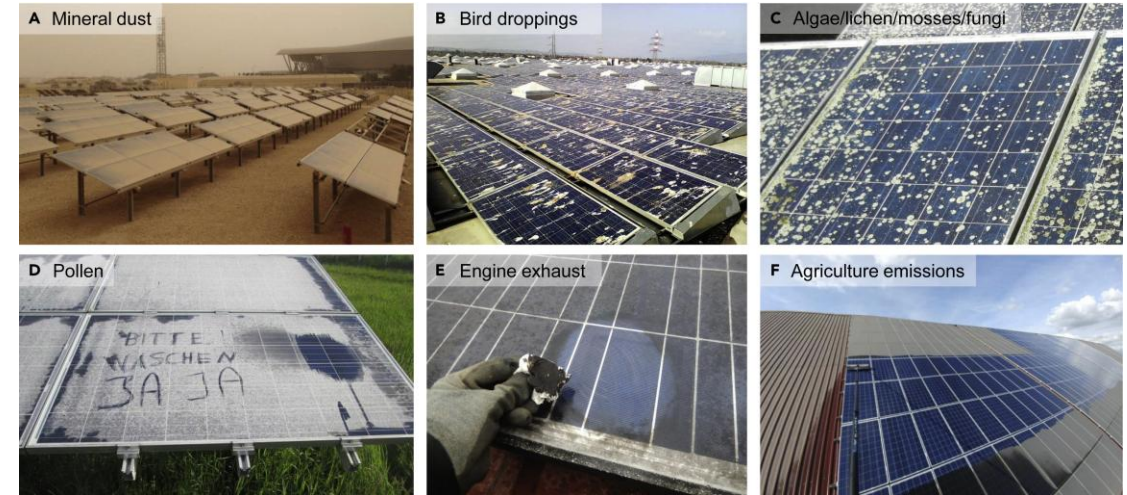
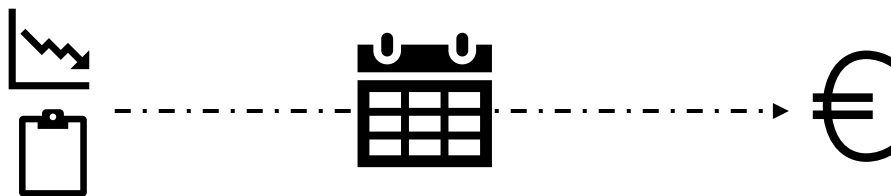
- **Soiling:** Accumulation of dust and other particles on PV panels.



- **Site-specific issue:** Soiling and its impacts vary widely depending on particle characteristics, PV layout, site surroundings and weather conditions.



- Accurate **soiling assessment** is essential to quantify energy losses, identify temporal & spatial patterns, and optimize cleaning strategies.



K.Ilse et al. (2019). "Techno-Economic Assessment of Soiling Losses and Mitigation Strategies for Solar Power Generation"
<https://doi.org/10.1016/j.joule.2019.08.019>



Background

Soiling in APV

In **agrivoltaic (APV)** systems, the impact of soiling on PV performance can be higher* than in conventional ground-mounted PV installations.¹ ***But also lower in some cases → comparison with bare soil without vegetation!**

- Dust and aerosol particles released during agricultural management practices can intensify soiling → the scheduling of cleaning activities needs to be coordinated with farming operations.



- Risk of sticky soiling related to pollen accumulation and/or the use of fertilizers and pesticides → Soiling type²

Soiling type + cleaning by rain²



Customized
cleaning products



Biodegradable and protective cleaning
solutions for modules installed at APV sites
developed by *Chemitek Solar*.

1. Trommsdorff, M., et al. (2025). "Dual Land Use for Agriculture and Solar Power Production: Overview and Performance of Agrivoltaic Systems", IEA – PVPS Task 13. DOI:10.69766/XAEU5008
2. Ruiz-Donoso, E. et al. (2026). "Maps of long-term soiling losses in Europe considering a partial cleaning effect by rain", EPJ-PV, <https://doi.org/10.1051/epjpv/2026010>

Background

Soiling in APV

Despite the potential for high soiling losses in APV systems, the topic has received limited attention, with only two studies providing preliminary assessments.

Jung et al.¹ quantified soiling losses through I–V measurements of individual modules before and after cleaning in a elevated and fixed-tilt APV system in Chile.

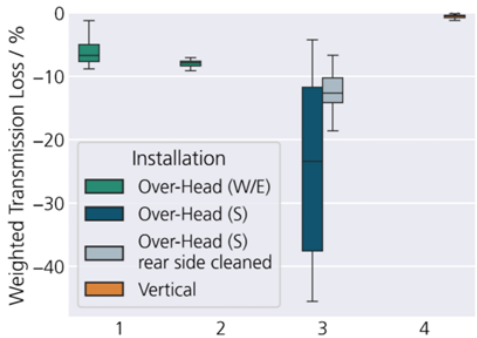


Main findings:

- Persistent soiling → An intense rain event did not restore losses to 0 (SL between 11% and 14%).
- Only 3.5 months after the rain event, they recorded SL of 30.7%.

Gebhardt et al.² assessed soiling by measuring transmittance losses of exposed glass samples across different APV configurations in several sites in Germany.

Site	APV Layout	Exposure
1	Overhead	Feb – Sep
2	Overhead + Tracker	Feb – Sep
3	Overhead	Jun – Nov
4	Vertical	Mar – Aug



Main findings:

- Strong variability across configurations and sites.
- Negligible losses in the vertical APV layout.

Important research gap → Lack of long term monitoring of soiling losses in different APV systems and agricultural environments

1. D. Jung, et al. (2022). "Effects of soiling on agrivoltaic systems: Results of a case study in Chile". DOI: 10.1063/5.0107943/2830593
2. P. Gebhardt, et al. (2025). "Evaluating the impact of soiling on agrivoltaic systems," in EU PVSEC 2025, Bilbao, 2025. DOI: 10.4229/EUPVSEC2025/3AV.3.31.

Aim of the study

- ❓ **Research question 1:** What is the **magnitude** of soiling losses in APV systems?
- ❓ **Research question 2:** Do **agricultural activities** increase soiling?
- ❓ **Research question 3:** Can **rain** act as an effective natural cleaning agent?

↓

First continuous, sensor-based assessment of soiling losses in APV systems using data from two European sites in Denmark and Spain



EXPERIMENTAL SITES AND METHODOLOGY

Experimental sites

Two European sites with different climates, system configurations and agricultural practices

Flakkebjerg - DK

- Temperate oceanic climate with frequent precipitations.
- Large – scale APV system: 1 MWp and 2.1 ha.
- Horizontal single-axis trackers.
- Arable crops (wheat, barley, beans and oats)
- Highly mechanized and automated agricultural management.



Laujar - ES

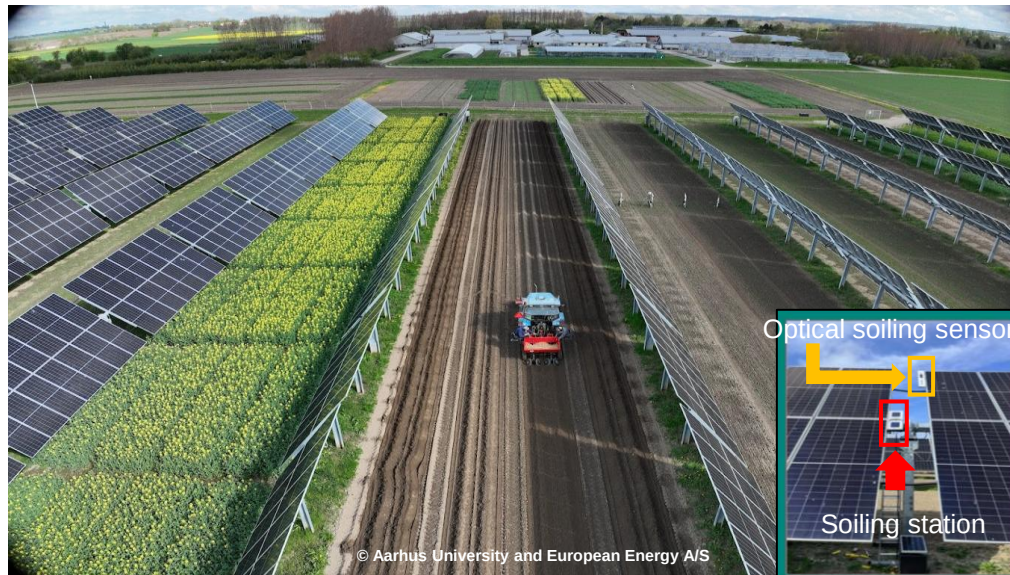
- Hot-summer mediterranean climate with scarce precipitations.
- Research – scale: 10.4 kWp and 0.015 ha.
- Elevated fixed-tilt system.
- Vineyard – Non irrigated.
- Mostly manual and ecological agriculture management.



Methodology

Both sites have automated soiling stations* that provide daily irradiance-weighted soiling losses

- Two reference cells:
 - ❑ Clean → Automatically cleaned daily using pressurized distilled water.
 - ❑ Soiled
- Irradiance (G) and cell temperature measurements are recorded at 2-min intervals.
- Soiling Loss (SL) = $1 - \text{Soiling Ratio} = 1 - G_{\text{soiled}} / G_{\text{clean}}$
- The daily average irradiance-weighted SL is calculated by weighting the SL by incident irradiance over the day (the higher the irradiance the greater the weight given to the datapoint).



Methodology

Monitoring data: Soiling-loss time series + precipitation + tracker (TCU) information*

Flakkebjerg: 11 Apr 2025 - 16 Aug 2025 (16 months); Laujar: 19 Jul 2025 - 16 Aug 2026 (13 months)

Identification of dry periods

- ≥ 14 consecutive days
- Daily precipitation < 0.1 mm

Soiling magnitude and patterns

- Soiling-loss profile
- Soiling rate (ΔSL [%/day])

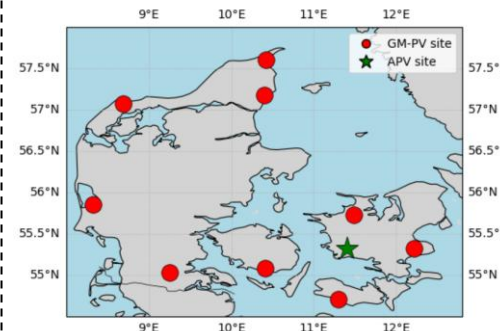
Identification of agricultural activity*

- Trackers move to $\pm 55^\circ$ during tractor activity in between rows, with inclination and status data triggering the TCU's "agri-mode" counter.
- Days with low and intense agricultural activity are those with ≥ 10 and ≥ 20 trackers in that mode, respectively.

Comparison of soiling impacts between APV and conventional ground-mounted (GM) PV installations

Denmark

- Assessment of soiling loss measurements in 9 GM-PV sites across the country. Use of an optical soiling sensor.
- Special focus on periods with intense agricultural activity.



Spain

- Comparison with a GM-PV installation located 60 km from the Laujar APV site.



**only in Flakkebjerg*



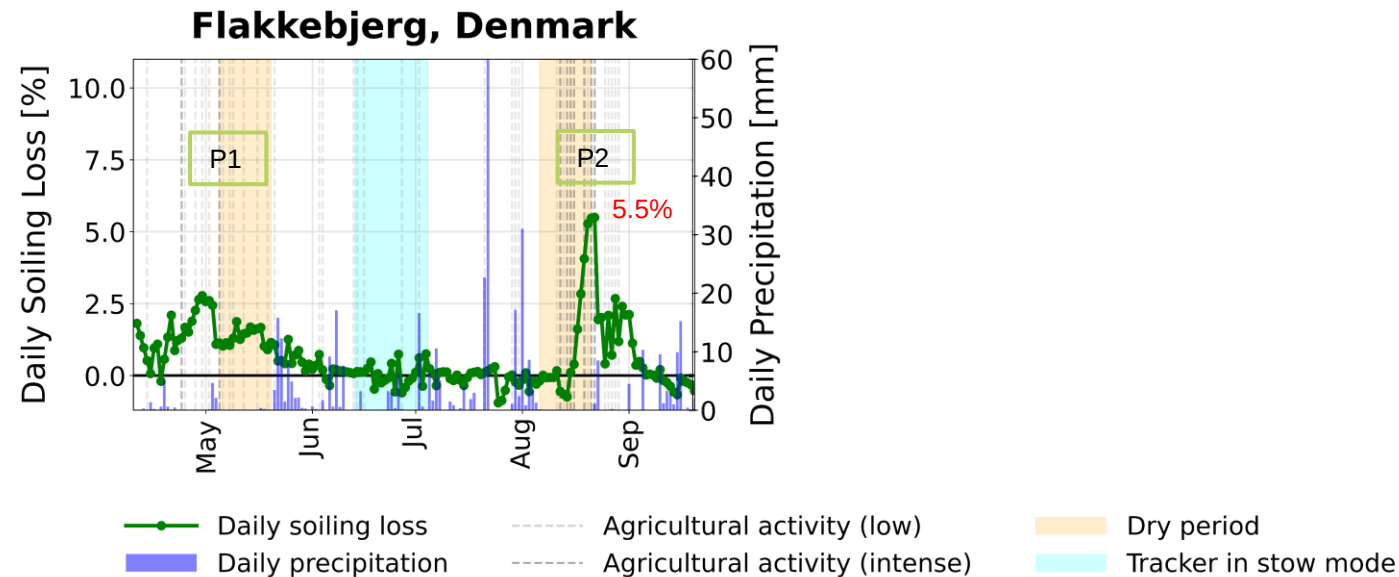
RESULTS

Results

Soiling profiles

Flakkebjerg - DK

- Higher soiling rates (up to 0.35%/day) during periods of frequent and intense agriculture activity.
- Local soiling peaks during these periods. Maximum SL of 5.5% in P2.
- Potential persistent soiling, with limited cleaning by rainfall (beginning of May – P1 and end-August – P2).



Results

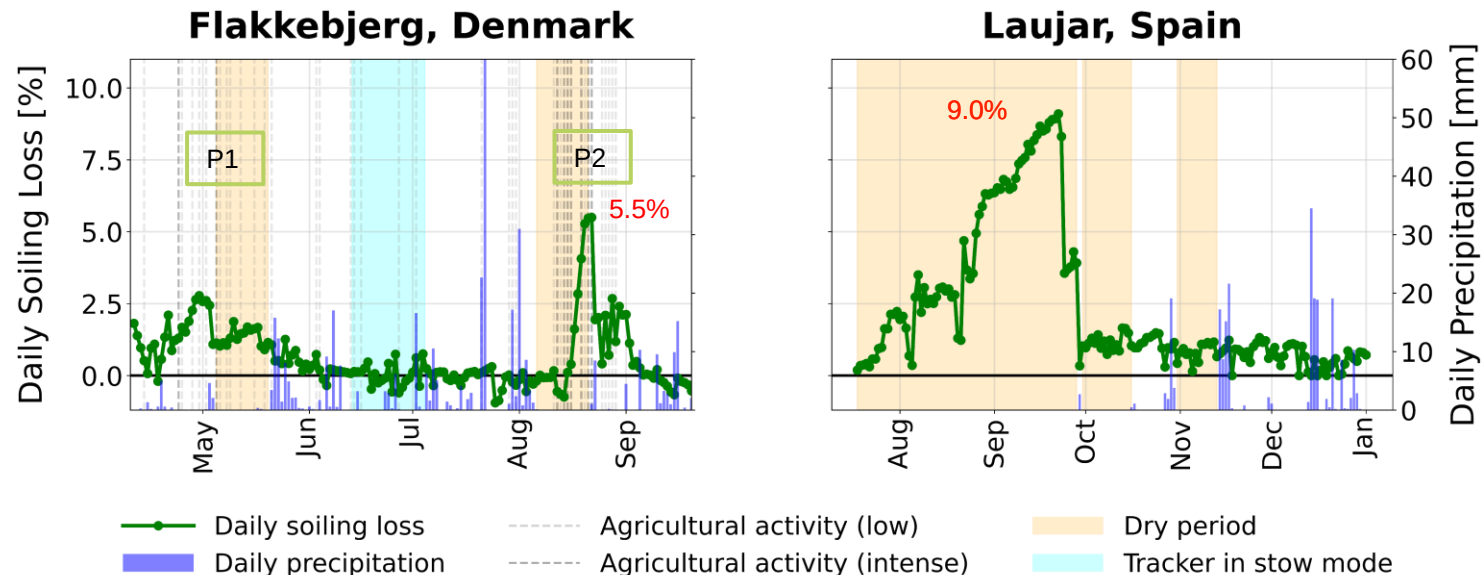
Soiling profiles

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Laujar - ES

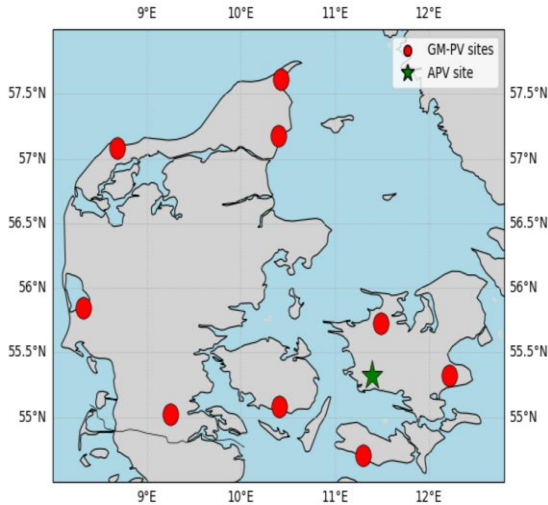
- Long summer dry spell that led to a steady accumulation of soiling → Peak loss of 9%.
- Soiling rate of 0.13%/day during that period.
- Lack of mechanized farming activities → Dust resuspension was not the main driver of soiling.



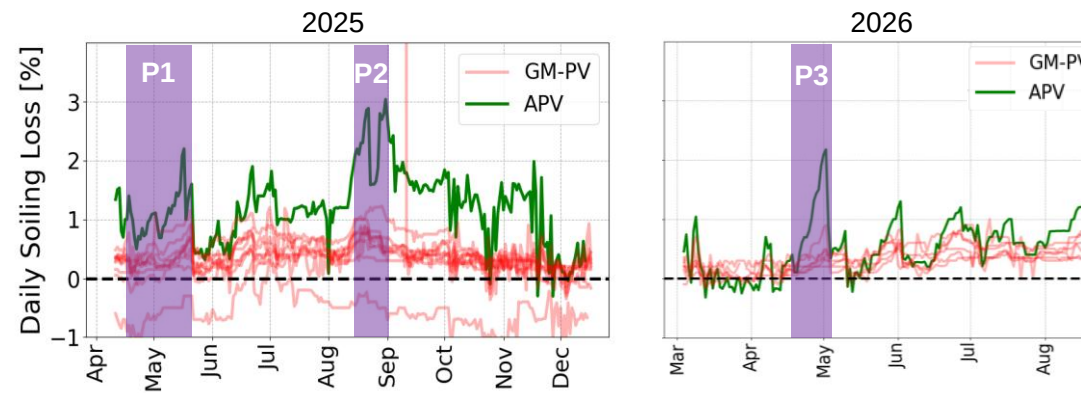
Results

Comparison between APV and GM-PV sites

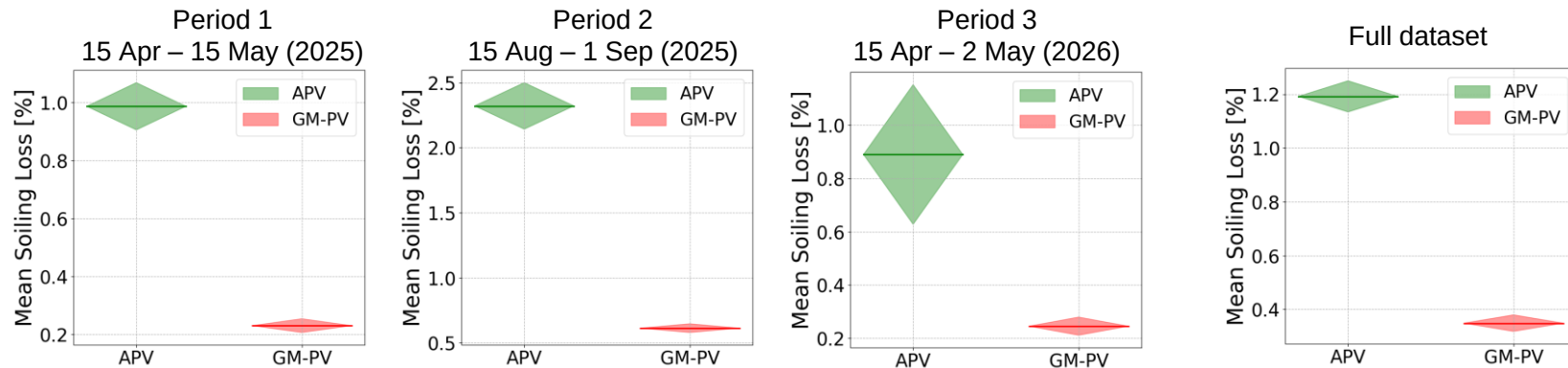
Denmark



- Red markers represent conventional GM-PV sites (most of them with 1-axis trackers)
- The green star represents the Flakkebjerg APV site.



Peak soiling loss values at the APV site were x2 (P1) and x3 (P2 & P3) higher than at conventional GM-PV sites.

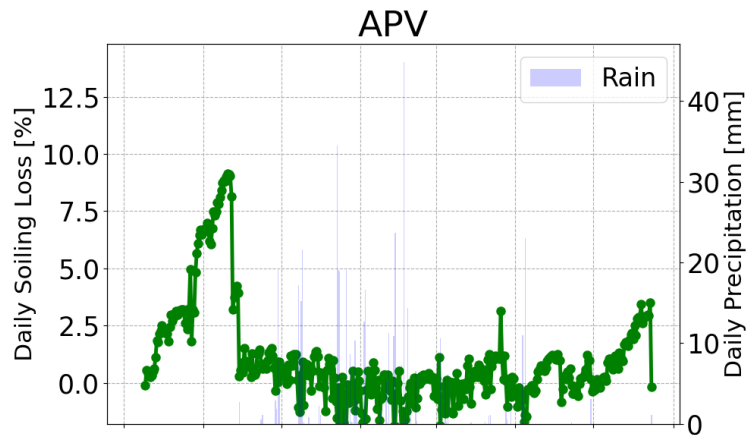


The APV site showed statistically significantly higher (x4) mean soiling losses than the conventional sites.

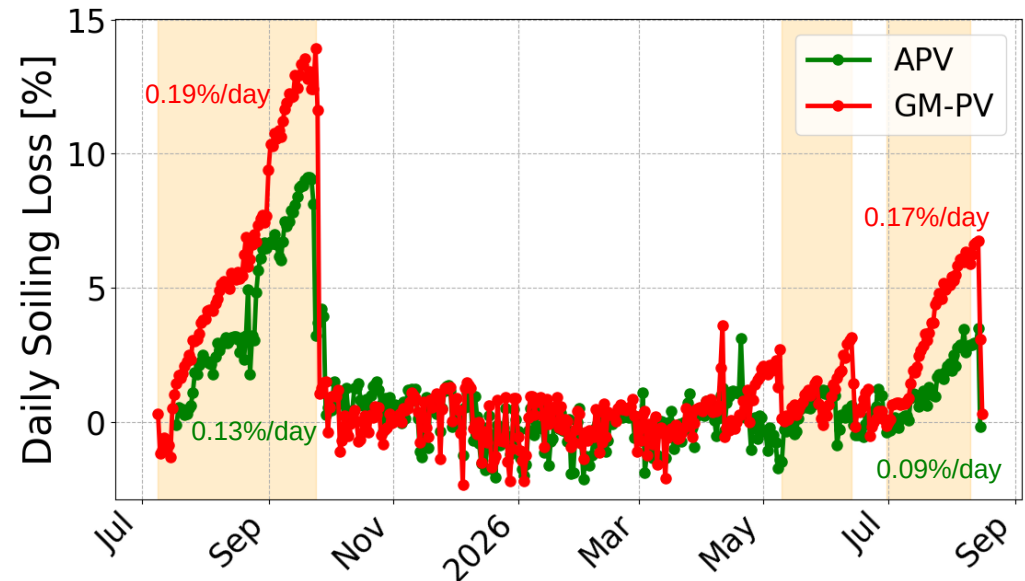
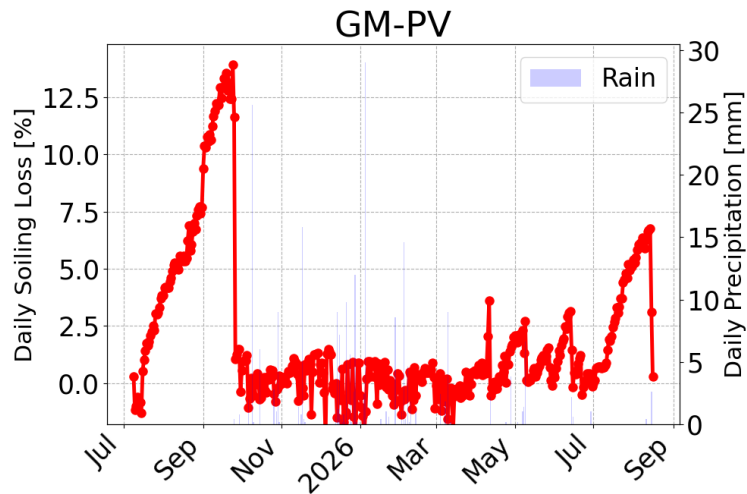
Results

Comparison between APV and GM-PV sites

Southern Spain

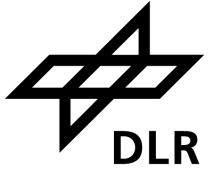


- Comparison of the soiling losses between two sites: Laujar (APV) and PSA (GM-PV fixed tilt).
- Same pattern at both sites, with a steady increase of the soiling loss during the dry summer period.
- Higher soiling rates (up to 0.19%/day in 2025) at the GM-PV site (bare soil) than at the APV site (lack of mechanized agriculture).



CONCLUSIONS

Conclusions



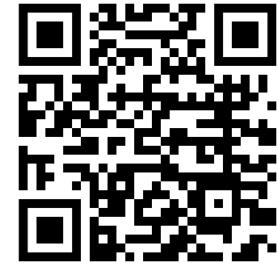
- **First continuous, sensor-based monitoring** of soiling losses in APV systems. Previous studies evaluated soiling through periodic soiling characterization.
- **Agricultural activities can increase soiling**, with strong effects on loss magnitude and accumulation rates.
- But, **soiling in APV is also configuration- and agricultural management- dependent**: The use of large machinery, irrigation via sprinklers or the application of fertilizers can lead to **higher losses**, even in **regions typically considered soiling-free**.
- Higher risk of **persistent soiling**, which is not effectively removed by rainfall, and **bird droppings**.
 - Optimization of cleaning methods → Effective and crop-friendly.
- **Next steps**:
 - Expand soiling monitoring across APV configurations, climates and management practices.
 - Optimize cleaning schedules and techniques considering soiling, agricultural activities and crops.
 - Evaluate how different crops and APV configurations affect soiling patterns, including rear-side soiling.

Thanks for your attention!

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connect on
LinkedIn



CORTIJO EL
CURA
Eco - Bodega

