MAPPING PV SOILING LOSSES IN EUROPE THROUGH AN ENVIRONMENTAL-BASED MODEL

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Images captured in Jaén, Spain, after a Saharan dust event in March 2022

BACKGROUND

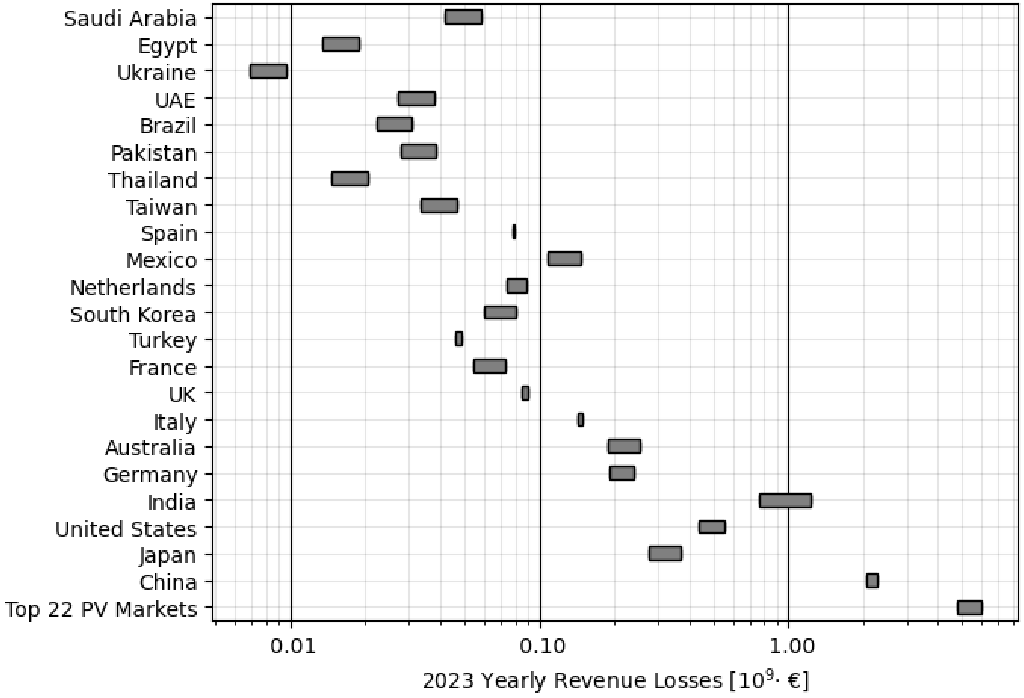
Background

Soiling impact

Last year, the annual revenue losses due to soiling in PV systems were estimated to be at least **5 billion €.**

The forecasted **increase** in the **PV capacity** in the next years will **multiply the losses** due to soiling.

Some scenarios indicate global annual soiling losses > **15 billion €** in **2026.**



Economic losses due to soiling

Data sourced from International Energy Agency – Task 13 Report (2022) "Soiling Losses – Impact on the Performance of Photovoltaic Power Plants" [1[.

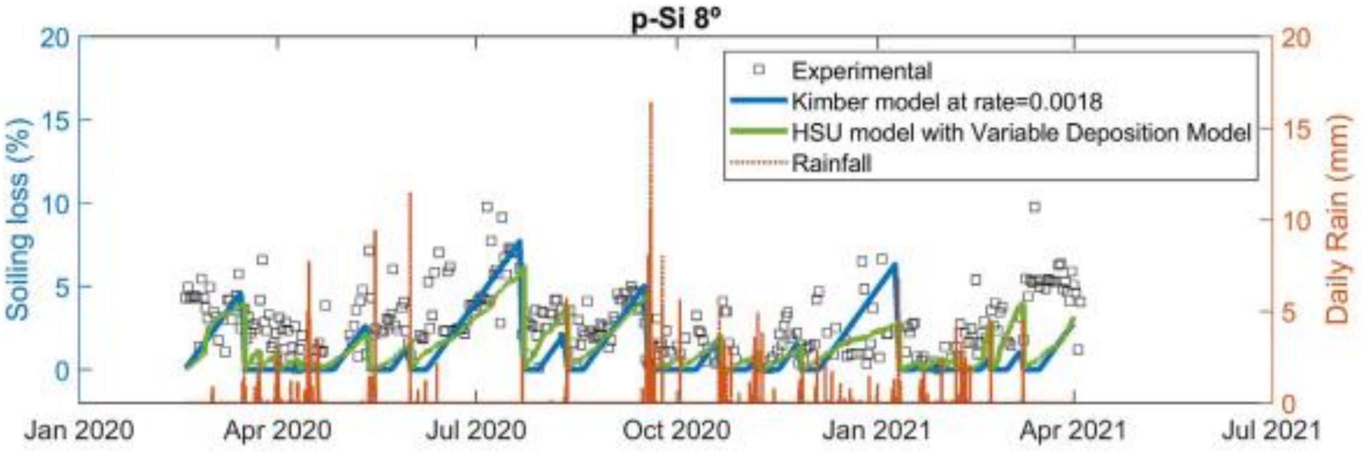
[1] IEA PVPS Task 13 (2022), "Soiling Losses – Impact on the Performance of Photovoltaic Plants", https://iea-pvps.org/wp-content/uploads/2023/01/IEA-PVPS-T13-21-2022-REPORT-Soiling-Losses-PV-Plants.pdf

Background

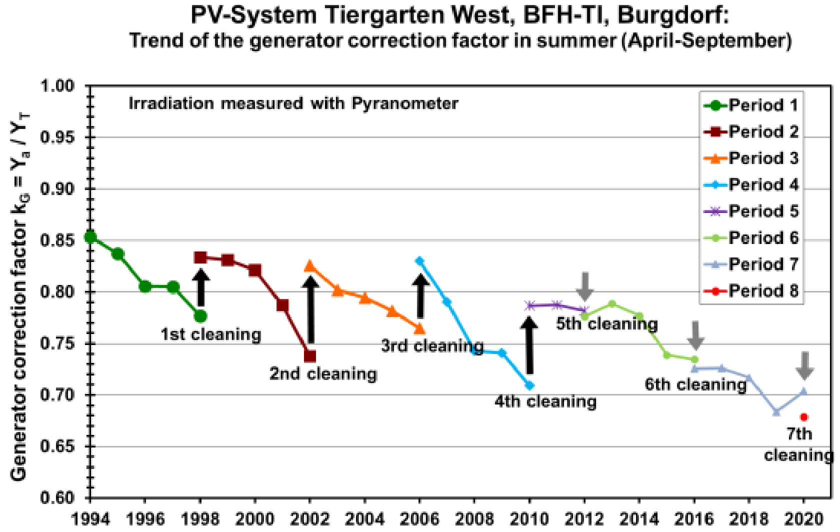
Soiling impact: Europe

The impact of soiling on PV has been typically overlooked in Europe.
Rainy locations were commonly considered as soiling-free.

Fortunately, this is starting to change! ☺



Assessment of two different PV soiling models against actual soiling measurements in a suburban area in Madrid, Spain [1].



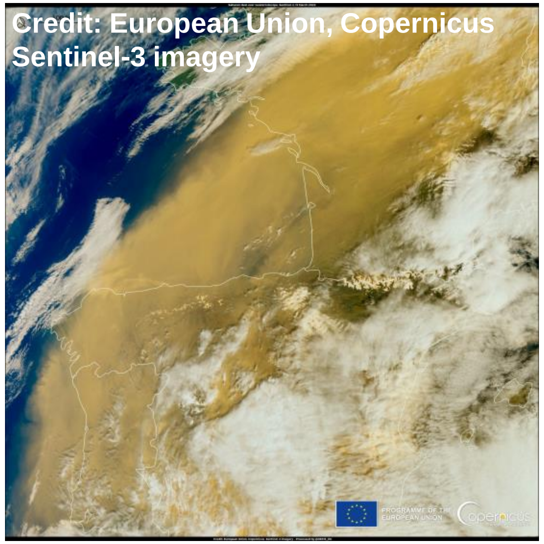
Important soiling losses in a PV system near a railway station in Switzerland - site with frequent and important precipitation events [2].

[1] J. Polo et al. (2021), “Modeling soiling losses for rooftop PV systems in suburban areas with nearby forest in Madrid”, Renewable Energy, https://doi.org/10.1016/j.renene.2021.06.085
[2] IEA PVPS Task 13 (2022), “Soiling Losses – Impact on the Performance of Photovoltaic Plants”, https://iea-pvps.org/wp-content/uploads/2023/01/IEA-PVPS-T13-21-2022-REPORT-Soiling-Losses-PV-Plants.pdf

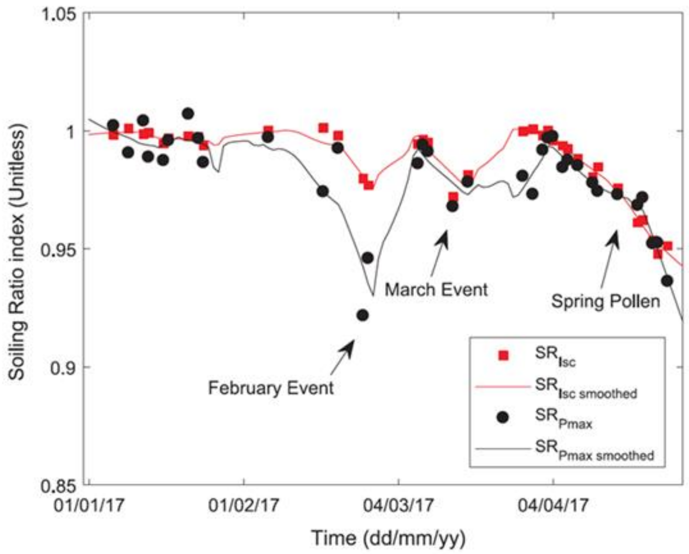
Background

Soiling impact: Europe

Increase in both the frequency and intensity of Saharan dust intrusions over the Western Mediterranean in the last decades [1].



A Saharan dust cloud engulfing the skies over France, Spain and Portugal on 15 March 2022.



Impact of two Saharan dust intrusions on the soiling profile of a site located in Évora, Portugal [2].

[1] P. Salvador et al. (2022) , "Increasing atmospheric dust transport towards the western Mediterranean over 1948–2020," https://doi.org/10.1038/s41612-022-00256-4
[2] R. Conceição et al., "Saharan dust transport to Europe and its impact on photovoltaic performance: A case study of soiling in Portugal," https://doi.org/10.1016/j.solener.2017.11.059

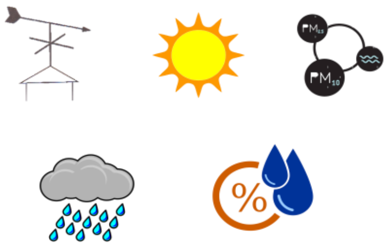
Background

PV Soiling Modelling

Use of environmental-based models to estimate the soiling losses in PV systems

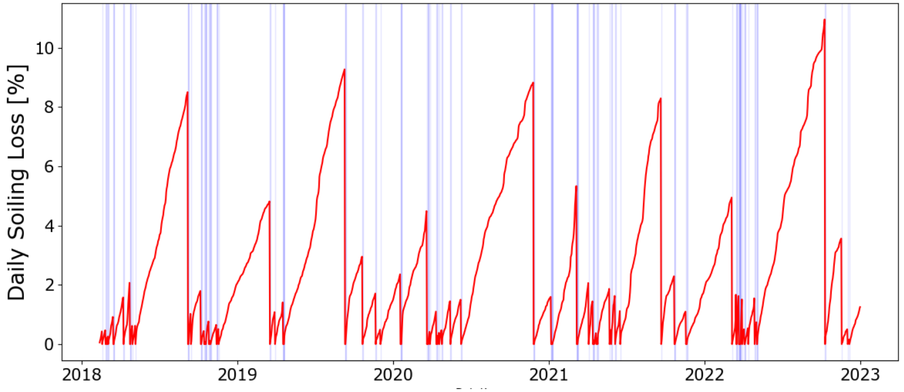
✓It makes possible to know the impact of soiling at a site prior to the PV system installation

1 Analysis of environmental parameters and PV system configuration



2 Calculation of the dust density accumulation

3 Calculation of the soiling losses



Research Question

Soiling magnitude, Soiling variability

What are the magnitude and variability of soiling losses in PV systems across Europe?

- First continental assessment: energy implications of soiling in PV.
- Application of a recalibrated environmental-based soiling model.

Images captured in Jaén, Spain, after a Saharan dust event in March 2022

METHODS

Methods

Soiling magnitude: HSU soiling model

It considers particulate matter (PM) concentrations and precipitation intensity as drivers of soiling accumulation/removal.

It assumes that a day with precipitation higher than a threshold restores the soiling loss to 0.
Sometimes, rain does not completely clean the modules & using a daily threshold may not be an accurate approach to model the soiling removal.

Soiling loss $$SL(d) = 0.3437 \cdot \mathrm{erf}(0.17 \cdot \omega(d)^{0.8473})$$

Accumulated mass density $$w(d) = \sum_{d_0}^{d} [(\boxed{v_{10-2.5}} \cdot PM_{10-2.5}) + (\boxed{v_{2.5}} \cdot PM_{2.5})] \cdot t \cdot \cos(\theta)$$

Settling velocities

Inputs
Databases of the Copernicus Atmosphere Monitoring Service (CAMS)

PM_{10} and $PM_{2.5}$	Rainfall
EAC4	ERA5

Methods

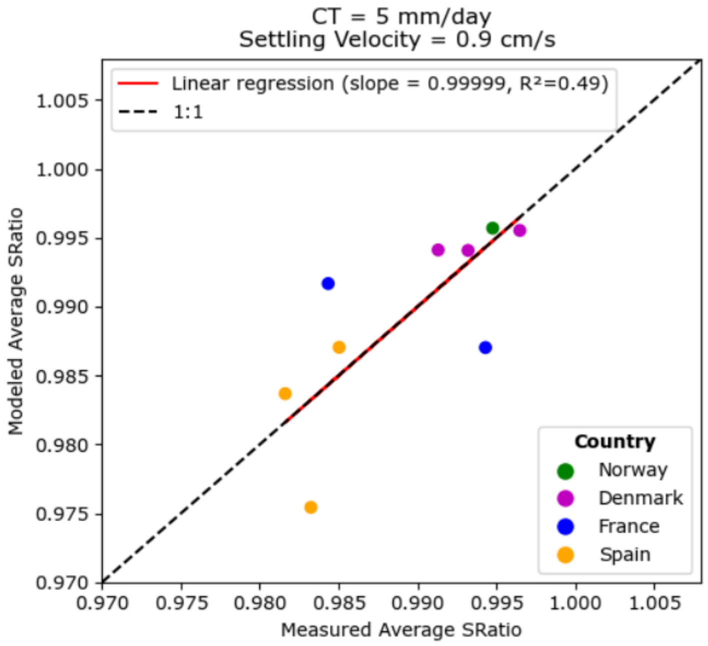
Soiling magnitude: Recalibrated HSU model

Calibration approach – Rain events totally clean PV modules (Perfect cleaning)

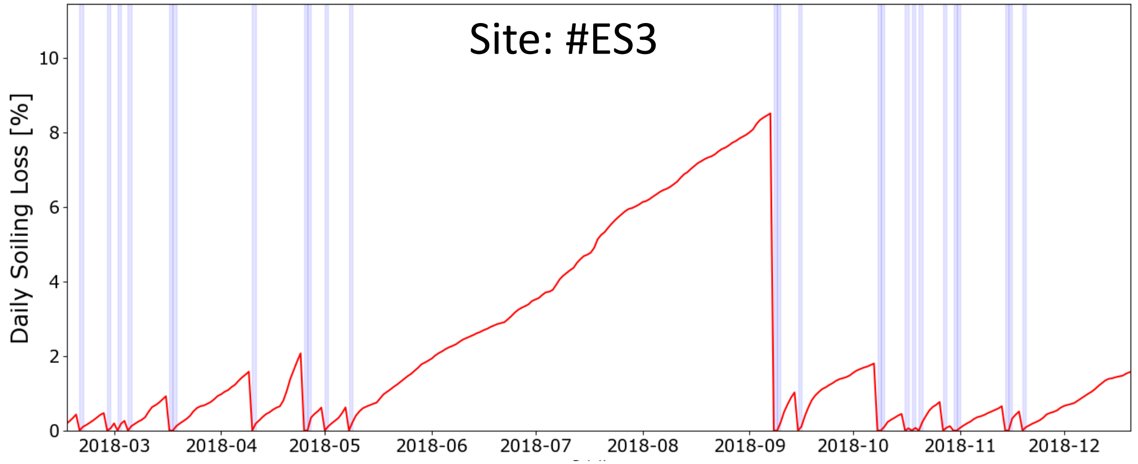
➢ Identification of the pair of values (cleaning threshold and settling velocity) that provides the best fit for the measured data.

Assumptions

- Single settling velocity → No difference between $PM_{10\text{-}2.5}$ and $PM_{2.5}$.
- We aimed **to apply the same settling velocity and the same threshold for all Europe** by tuning these parameters using measured soiling data from 9 different locations.



Site ID	Country	Soiling Sensor	Tilt angle [°]	Average Soiling Loss [%]	Time frame [Start – End] [dd/mm/YYYY]
DK1	Denmark	DustIQ	25	0.87	07/03/2020 – 03/03/2022
DK2	Denmark	DustIQ	25	0.68	17/03/2021 – 31/10/2022
DK3	Denmark	DustIQ	25	0.35	13/02/2020 – 18/10/2022
ES1	Spain	Atonometrics Soiling Station	30	1.50	01/03/2019 – 31/12/2022
ES2	Spain	DustIQ	8	1.84	27/02/2019 – 21/08/2021
ES3	Spain	DustIQ	45	1.68	13/02/2018 – 31/12/2022
FR1	France	DustIQ	6	1.57	17/10/2020 – 31/12/2022
FR2	France	DustIQ	Single Axis Tracker E-W	0.57	09/09/2021 – 31/12/2022
NO	Norway	DustIQ	46	0.52	24/04/2019 – 18/07/2022



Methods

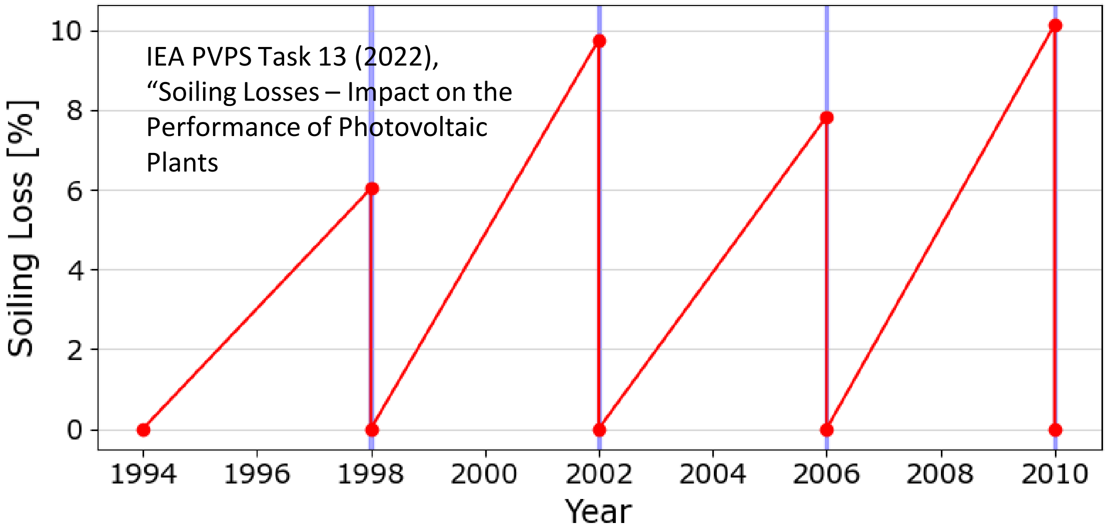
<u>**Soiling magnitude**</u>: Recalibrated HSU model

<u>Calibration approach – Rain events only remove a small part of the soiling (Partial cleaning)</u>

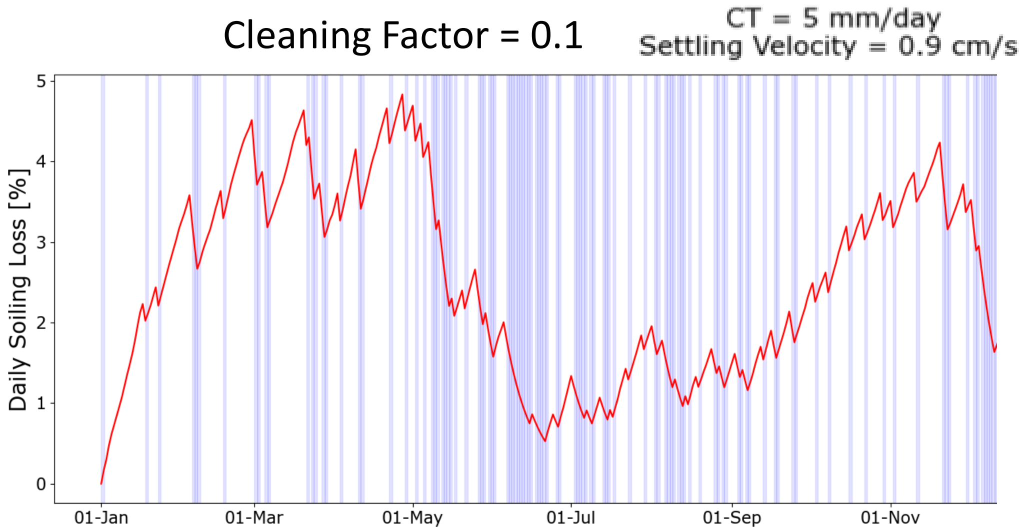
To assess the completeness of cleanings due to rain, we introduce a new parameter, called "**Cleaning Factor**" in the HSU model.

$$Cleaning\ Factor = 1 - \frac{accumulated\ mass\ after\ rainfall > CT}{total\ accumulated\ mass}$$

In this study, we calibrated this factor based on the data from a rainy location in Switzerland with high annual soiling losses.



Cleaning Factor = 0.1



Methods

Metrics: Soiling Variability

SVI: Soiling Variability Index

This metric is calculated as sum of the absolute deviations of the losses accumulated on a month from the monthly mean, divided by the total annual loss.

$$SVI(site) = \frac{\sum_{m=1}^{12} \left| S_m(m) - \frac{S_{m\_sum}}{12} \right|}{S_{m\_sum}}$$

$$S_{m\_sum} = \sum_{m=1}^{12} S_m(m) \qquad S_m(m) = \sum_{s=1}^{n_d} S_L(d)$$

CoV: Coefficient of Variation

This metric represents the interannual-variability of soiling losses. It is calculated as ratio of the standard deviation to the mean of the annual mean losses over the investigated period (2005-2019).

$$\mathrm{CoV}(site) = \frac{\sigma_{SL_y}}{\overline{SL_y}}$$

$$\sigma_{SL_y} \rightarrow Standard\ deviation \qquad \overline{SL_y} \rightarrow Mean\ soiling\ loss$$

The higher their values the greater the variability

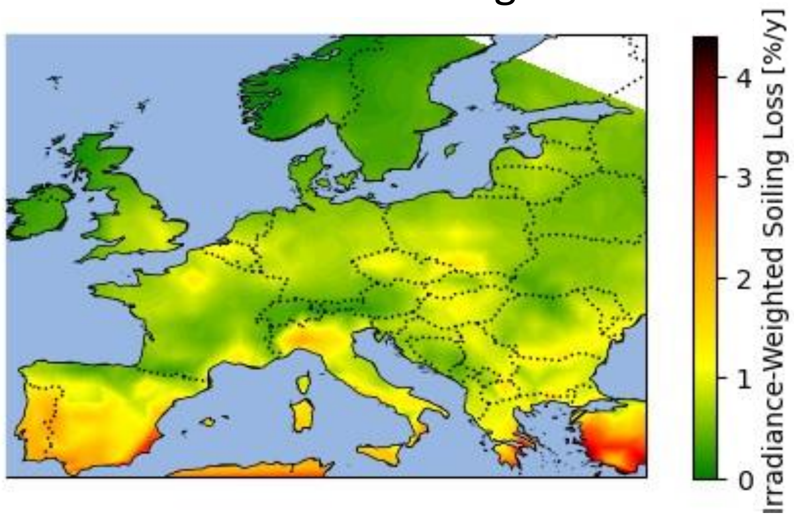

Images captured in Jaén, Spain, after a Saharan dust event in March 2022

RESULTS

Results

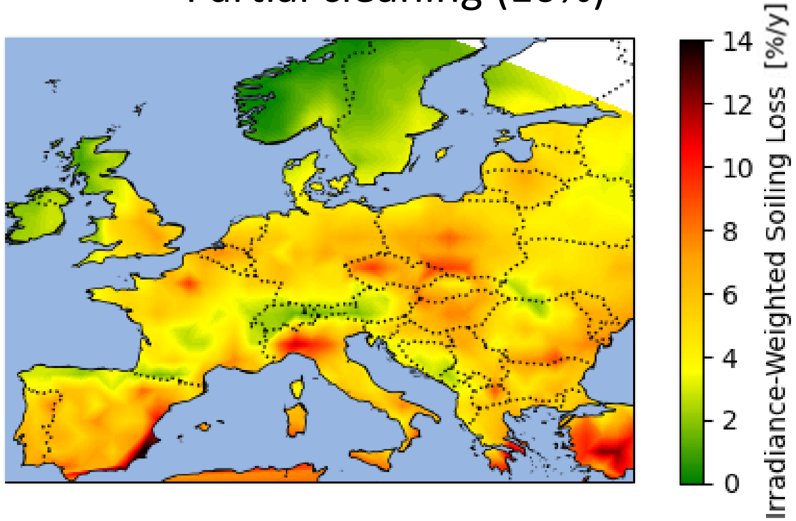
Soiling magnitude

Perfect cleaning



- Average annual soiling loss of 1.0%.
- Significant uneven distribution of losses across the continent.
  - Maximum annual losses of ~3.5% in some regions of the southernmost countries (Spain, Türkiye and Greece).
  - Minimum losses (<0.5%) in the northern countries (Sweden, Norway, Ireland)

Partial cleaning (10%)

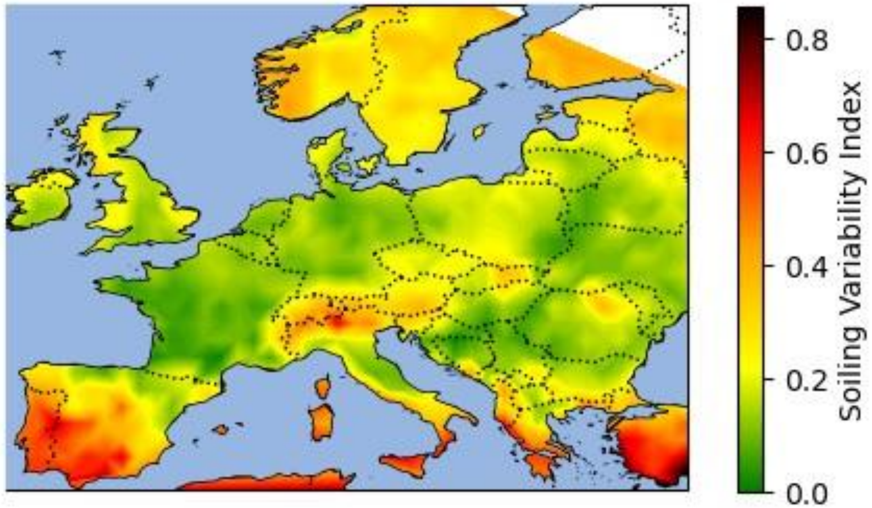


- Average annual soiling loss of 5.3%.
- Peaks > 10% in some regions of the southernmost countries (Spain and Türkiye).
- Minimum losses, with median values of ~3% in the northern countries.

Results

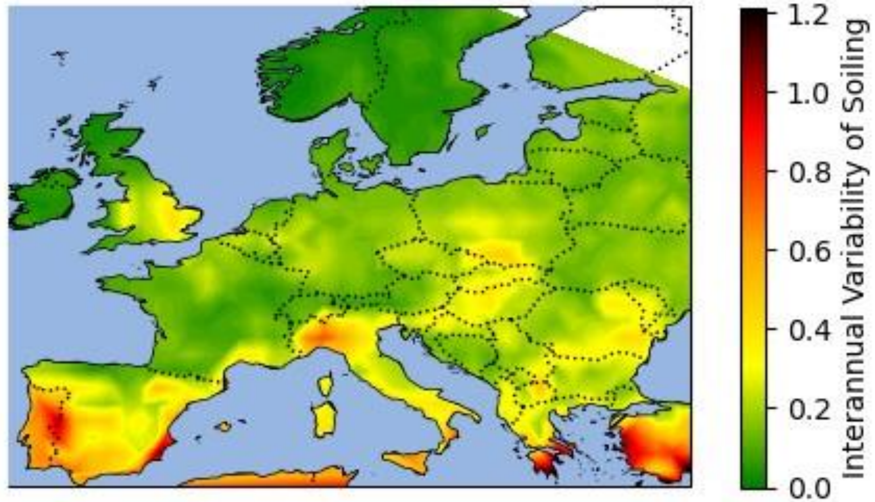
Soiling variability

Seasonality



- Clear contrast between southern and central and northern countries.
- High seasonality in the south (long and dry summers).
- Consistent losses in central Europe (France, Netherlands, Germany) due to frequent rainfalls over the year.
- The higher values in the Nordic countries can be due to the low soiling losses.

Interannual variability



- The larger the value, the higher the variability from one year to another.
- Locations with the highest losses are also those with the highest variability (losses can vary by more than 100% in some regions).
- The high variability in the southernmost countries may be due to the impact of Saharan dust intrusions, which can vary in magnitude and frequency from year to year.
- The lowest values (< 10%) are found in countries with lower losses, such as Ireland, Norway and Sweden.

Images captured in Jaén, Spain, after a Saharan dust event in March 2022

CONCLUSIONS

Conclusions

- Evaluation of both soiling magnitude and variability in Europe (regions with the highest losses are often those with the greatest seasonality and interannual variability).
- The results highlight the importance of soiling monitoring to assess the actual level of soiling.
- Limitations of current soiling models, particularly regarding the completeness of cleaning by rain.
- Future works should promote the adaptation and validation of models in soiling-prone sites (agrivoltaics, near railroads, close to certain factories…).

Both soiling modelling and soiling monitoring are required!

Thanks for your attention!

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