Effect of the environment on the PV performance

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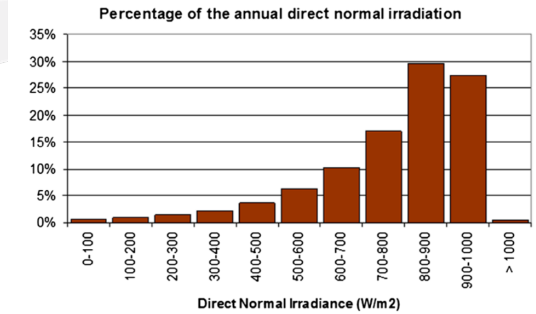
About the University of Jaén

Atmospheric conditions:

- Annual irradiation > 2000 kWh/m^2
- Air temperature: 0 to 45 ^{o}C
- Subject to seasonal soiling events due to dust storms and to olive harvesting activities



Advances in Photovoltaic Technology (AdPVTech)

Head : Dr. Eduardo F. Fernández

Aim of the group. Development, characterization and performance evaluation of PV technology.

Funded projects:

- *ROM-PV(SOLAR-ERA-NET)*
- *NoSoilPV(H2020-MSCA-IF-2017)*
- *HybridCPV200 (H2020-MSCA-IF-2019)*
- *UltraMicroCPV (AEI)*
- *NACe-CPV/TE(PAIDI 2020)*
- *DUSST (NREL)*
- *…*

+2 M€ within the last 5 years

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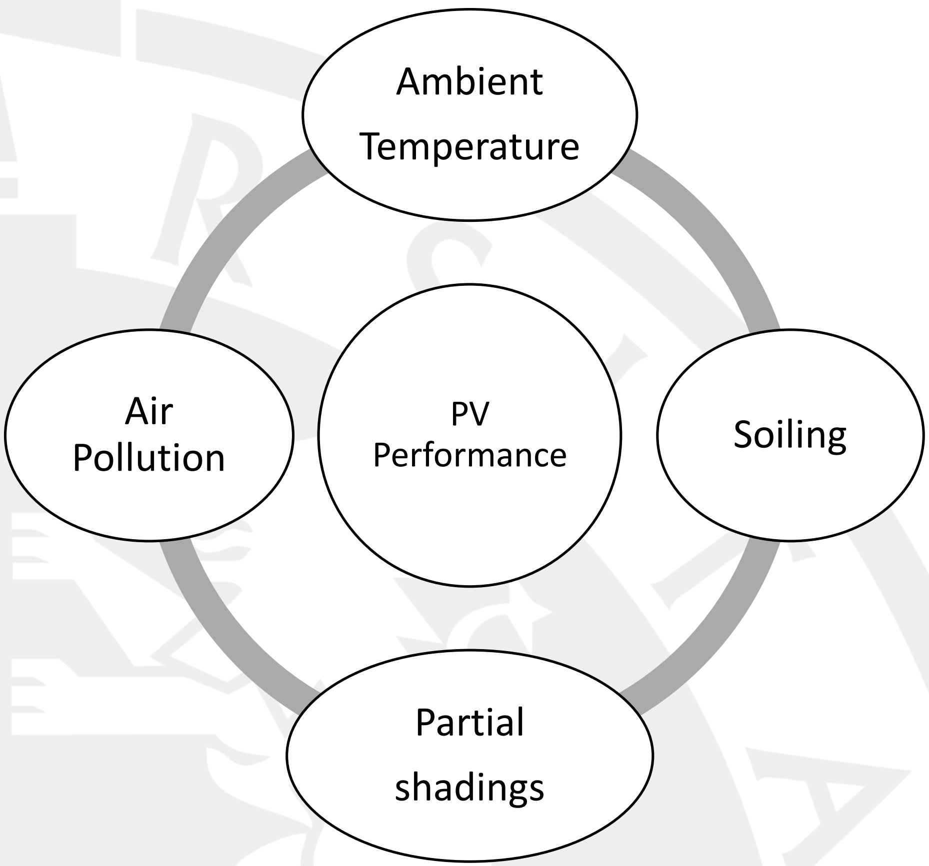
Agenda

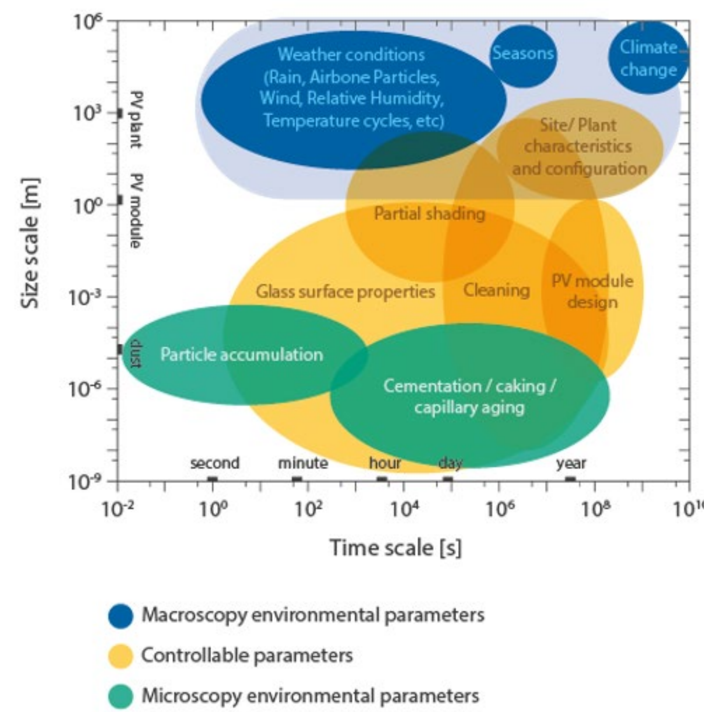
- Background
- PV Soiling Modelling concepts
- Experimental results
- Conclusion

Effect of the environment on the PV performance



Soiling

Process whereby dust, dirt and organic/inorganic contaminants deposit on the surface of a PV module.



Ilse, K.K., Figgis, B.W., Naumann, V., Hagendorf, C., Bagdahn, J., 2018. Fundamentals of soiling processes on photovoltaic modules. Renew. Sustain. Energy Rev. 98, 239–254. https://doi.org/10.1016/j.rser.2018.09.015

- Global effect of soiling in 2018 : 5 billion euros [2]
- Soiling is a reversible loss as can be removed artificially or naturally
- Tools to estimate soiling
  - Soiling monitors
  - Extraction algorithms
  - Estimation models

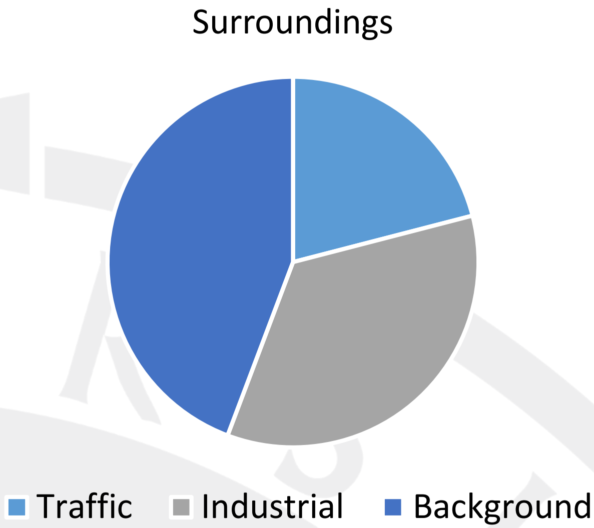
- Soiling metric
  - Soiling Ratio (value of 1 in absence of soiling and its value decreases as soiling deposits)
- Key soiling environmental predictors
  - Particulate matter and rainfall [3]
- Other environmental parameters related to deposition and removal process
  - Wind Speed, Relative humidity, ambient temperature [1]

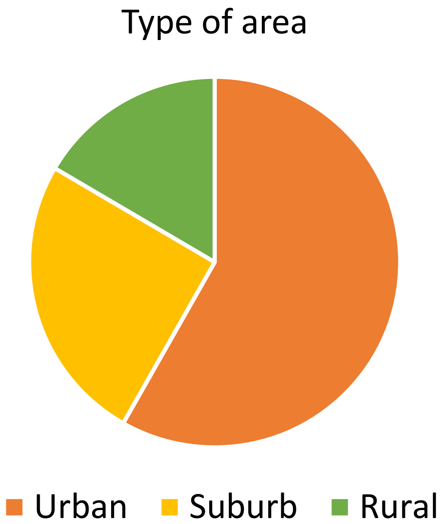
[1] Bessa, J.G., Micheli, L., Almonacid, F., Fernández, E.F., 2021. Monitoring Photovoltaic Soiling: Assessment, Challenges and Perspectives of Current and Potential Strategies. iScience 102165. https://doi.org/10.1016/j.isci.2021.102165

[2] Ilse, K., Micheli, L., Figgis, B.W., Lange, K., Daßler, D., Hanifi, H., Wolfertstetter, F., Naumann, V., Hagendorf, C., Gottschalg, R., 2019. Techno-Economic Assessment of Soiling Losses and Mitigation Strategies for Solar Power Generation 1–19. https://doi.org/10.1016/j.joule.2019.08.019

[3] Micheli, L., Muller, M., 2017. An investigation of the key parameters for predicting PV soiling losses. Prog. Photovoltaics Res. Appl. https://doi.org/10.1002/pip.2860

Air quality monitors in Spain





- Traffic : vehicles and roads/streets
- Industrial : Industrial sources
- Background : No predominant source

- Urban : located in continuous built-up areas
- Suburb : Built-up areas separated by non-urban zones
- Rural : Not urban or Suburb

Typically the available PM monitors are mainly located in urban areas while utility scale PV plants are typically located in less developed areas.

Air quality monitors in Spain

Monitored pollutants

- Sulphur dioxide (SO_2)
- Ozone (O_3)
- Nitrogen dioxide (NO_2)
- Carbon monoxide (CO)
- PM_{10}
- $PM_{2.5}$
- Others(e.g. Arsenic, Cadmium, Nickel, Benzene, Lead)

- The source of PM data can affect the estimation
  - Estimation results differences up to 2x in soiling modelling in USA using different PM sources.
- Ground-based and satellite-derived environmental parameters are typically available for more locations and longer time intervals than PV data series

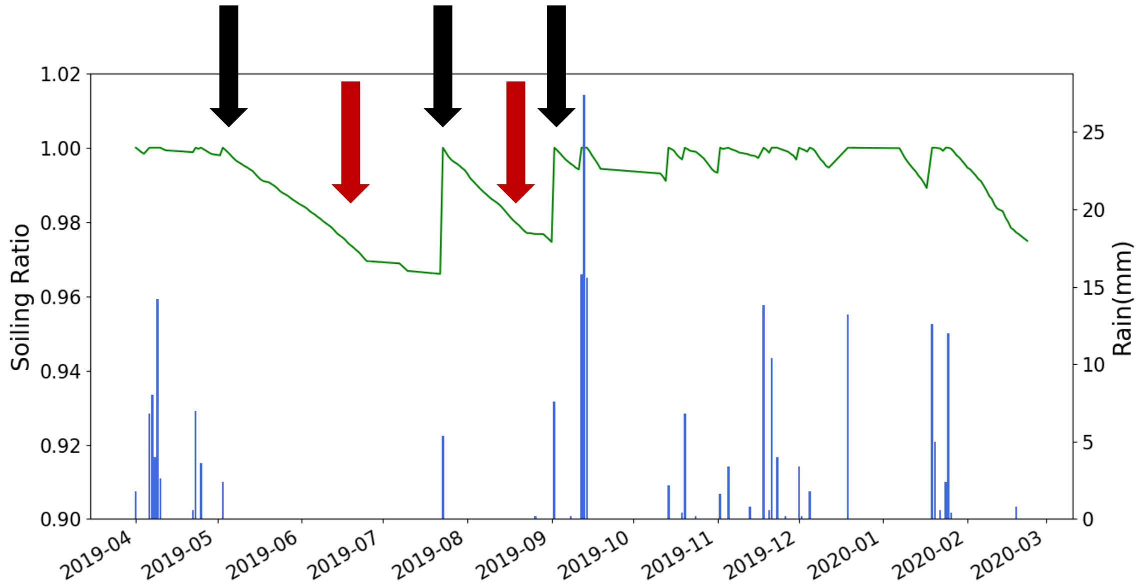
Micheli, L., Smestad, G.P., Bessa, J.G., Muller, M., Fernandez, E.F., Almonacid, F., 2021. Tracking Soiling Losses: Assessment, Uncertainty, and Challenges in Mapping. IEEE J. Photovoltaics 1–5. https://doi.org/10.1109/jphotov.2021.3113858

Research questions

- How can we estimate the soiling losses using environmental parameters?
- Are satellite-derived environmental parameters suitable for PV soiling modelling?

- Estimation models are based on: the variability of and the interaction between environmental parameters, as well site characteristics and system configuration

▪ Alternation of soiling periods, generating a saw-tooth wave



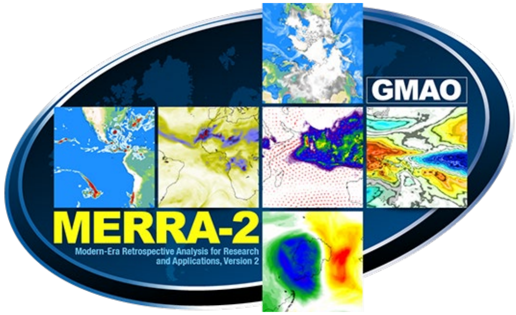
Natural cleaning

Cleaning threshold (CT)

Soiling accumulation

Interaction between environmental parameters:

- Particulate Matter
- Ambient Temperature
- Relative Humidity
- Wind speed



Source : https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/

Data

- Satellite data from MERRA-2
  - Constantly updated satellite data is available worldwide at fine temporal and spatial resolutions
  - PM is calculated using mixing ratios of :
    - Dust, Organic Carbon, Black Carbon and Sea Salt

Accumulation processes

- Particle deposition
  - Velocity deposition (V_d)
    - Gravitational settling
    - Wind turbulence
    - Boundary layer effects
  - Environmental inputs
    - Ambient Temperature
    - Wind Speed
    - Relative Humidity

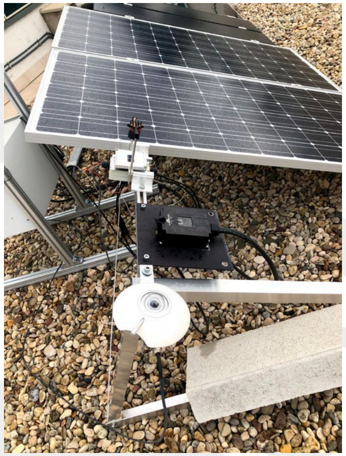
Existing models to estimate soiling losses from environmental parameters

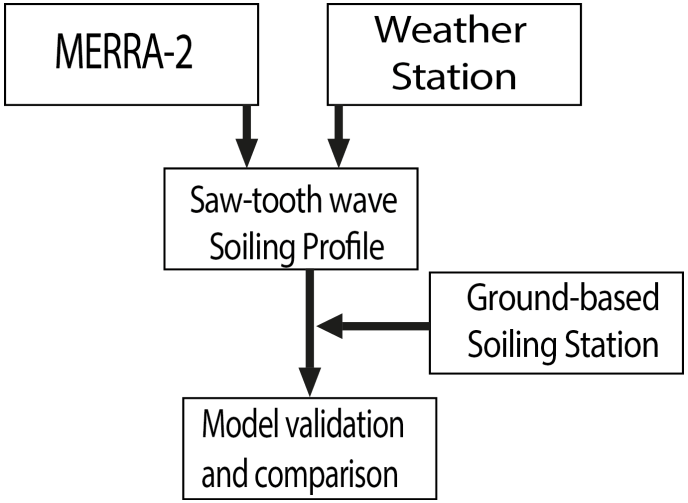
Coello [4]	Toth [5]	You [6]	Bergin [7]
• $PM_{10-2.5}$ • $PM_{2.5}$ • V_d	• PM_{10} • $PM_{2.5}$ • A_1, A_2	• PM_{10} • $PM_{2.5}$ • V_d	• Dust • OC • BC • SS • $E_{abs,i}$, β_i , $E_{scat,i}$

A_1, A_2 - constants fitted in the model
$E_{abs,i}$ - mass absorption efficiency
β_i - PM upscatter fraction
$E_{scat,i}$ - mass scattering efficiency

[4] Coello, M., Boyle, L., 2019. Simple Model for Predicting Time Series Soiling of Photovoltaic Panels. IEEE J. Photovoltaics 9, 1382–1387. https://doi.org/10.1109/JPHOTOV.2019.2919628
[5] Toth, S., Hannigan, M., Vance, M., Deceglie, M., 2020. Predicting photovoltaic soiling from air quality measurements. IEEE J. Photovoltaics 1–6.
[6] You, S., Lim, Y.J., Dai, Y., Wang, C.H., 2018. On the temporal modelling of solar photovoltaic soiling: Energy and economic impacts in seven cities. Appl. Energy 228, 1136–1146. https://doi.org/10.1016/j.apenergy.2018.07.020
[7] Bergin, M.H., Ghoroi, C., Dixit, D., Schauer, J.J., Shindell, D.T., 2017. Large Reductions in Solar Energy Production Due to Dust and Particulate Air Pollution. Environ. Sci. Technol. Lett. 4, 339–344. https://doi.org/10.1021/acs.estlett.7b00197

Experiment conducted at the rooftop of CEACTEMA at the University of Jaén.





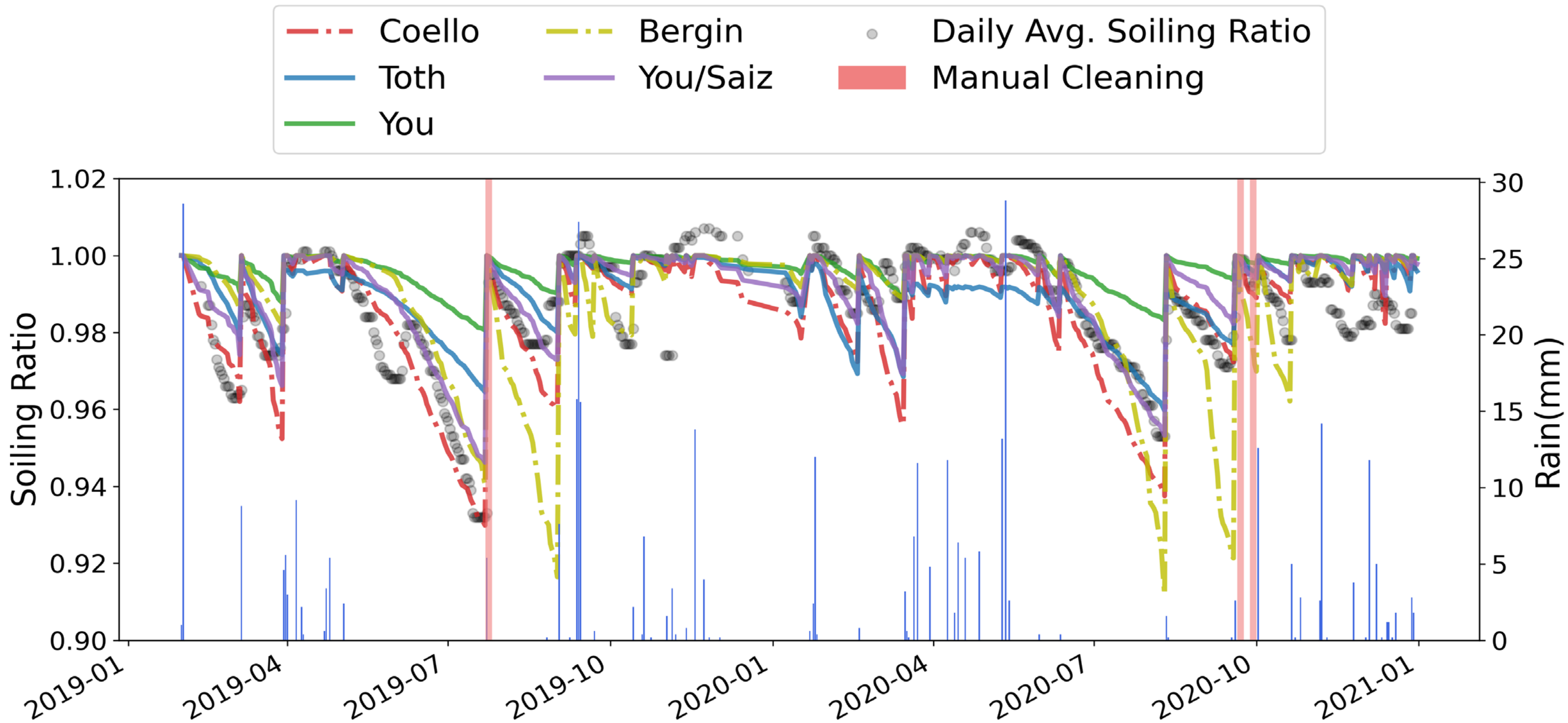
Database source

- MERRA-2
  - Particulate Matter
  - Rainfall
- Local weather Station
  - Ambient Temperature
  - Relative humidity
  - Wind Speed
  - Rainfall

Validation

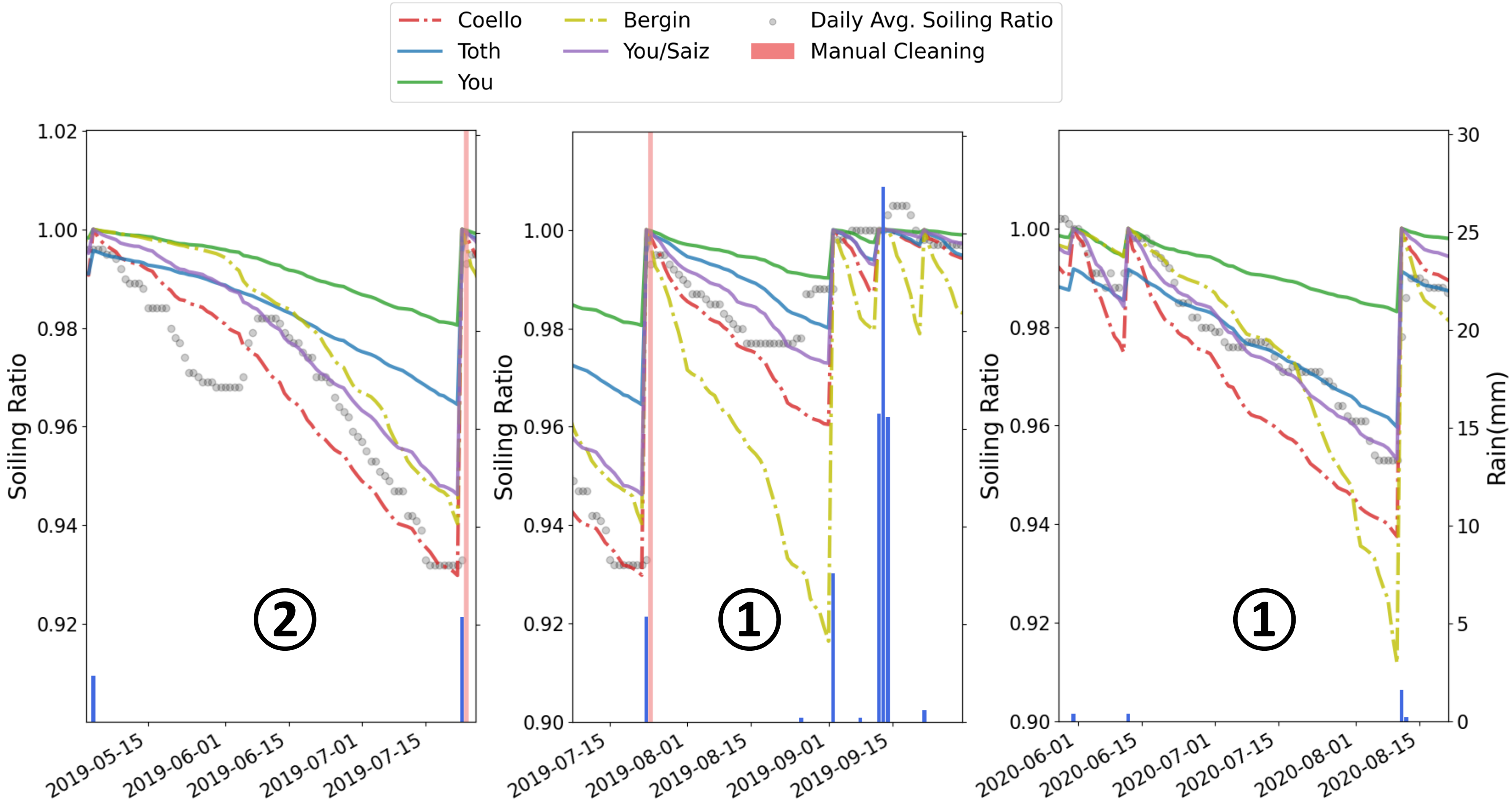
- Ground-based commercial soiling station
  - Soiling Ratio time series
- Cleaning Threshold
  - Estimation using different cleaning thresholds

- All models could capture the soiling seasonality for Jaén

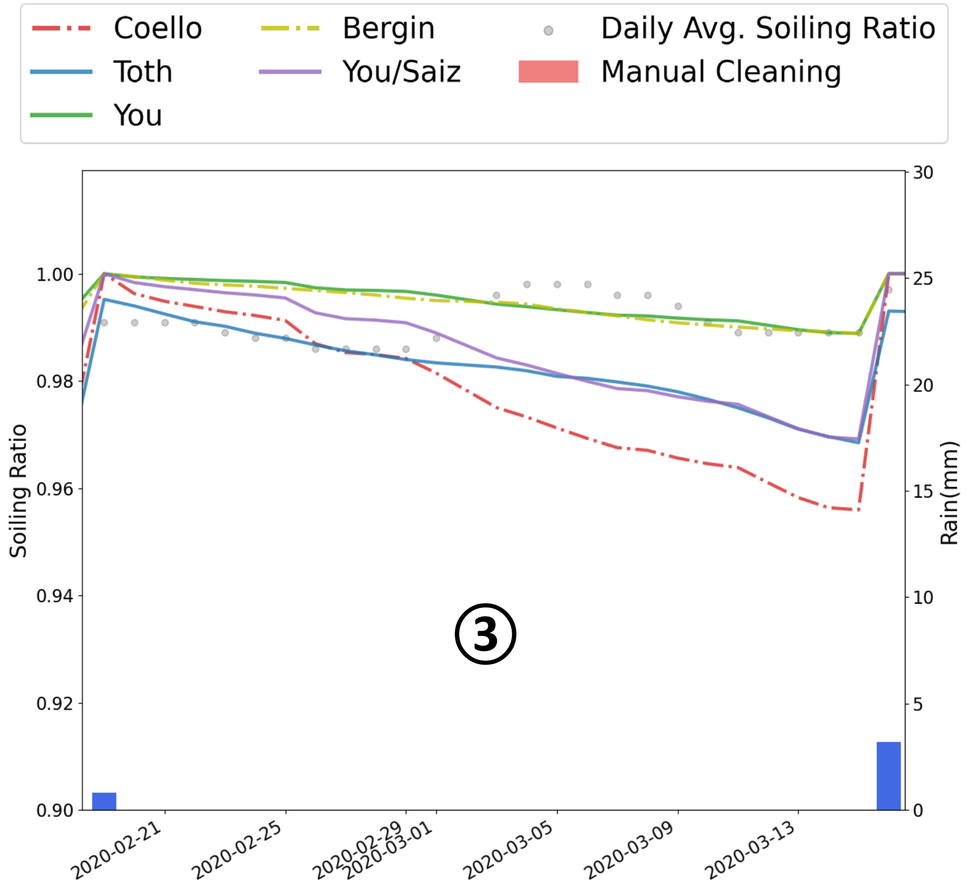


Modeled soiling profiles using as cleaning threshold 0.3 mm day^{-1} and the extracted soiling profile from a soiling station installed in Jáen, Spain.

Results

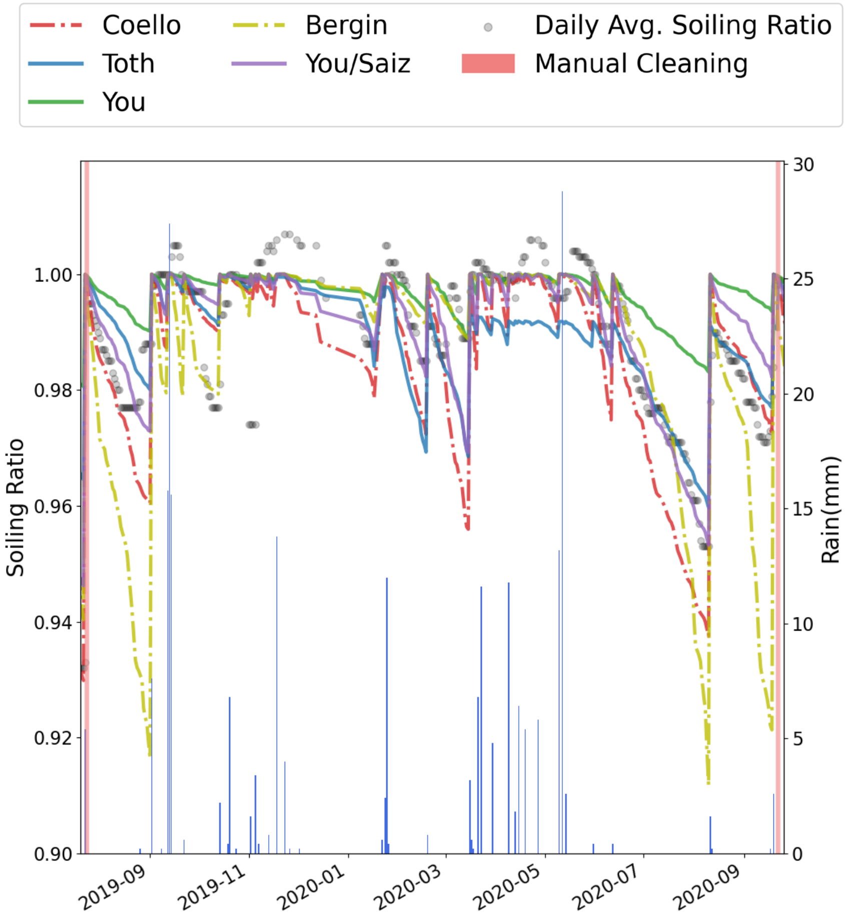


- Bergin's model overestimated the losses up to 4%
  - Comparing period ① to period ② – 61% increase in the organic carbon mass accumulation
  - High organic carbon concentrations can lead to overestimation modelling due to its light attenuation properties



- Coello, Toth and You/Saiz overestimated losses in the dry period ③
- Optical properties of PM components in Jaén
  - Dust property could be applied
  - OC, BC and SS properties may not be suitable
- Seasonality observed in the scattering and absorption efficiencies of PM for southern Spain[8].

[8] Titos, G., Foyo-Moreno, I., Lyamani, H., Querol, X., Alastuey, A., Alados-Arboledas, L., 2012. Optical properties and chemical composition of aerosol particles at an urban location: An estimation of the aerosol mass scattering and absorption efficiencies. J. Geophys. Res. Atmos. 117, 1–12. https://doi.org/10.1029/2011JD016671



- Offest observed in Toth model
  - Sticky nature of the fine particles
  - Sites with high fine particle concentrations : India, Saudi Arabia, Egypt and Iran
- You model is the greater underestimation model
  - Low rate of reduction of efficiency reduction by dust deposition assumed

Accepted, In Production : Estimation of Photovoltaic Soiling using Environmental parameters: A comparative analysis of existing models, Advanced Sustainable Systems,**DOI:** 10.1002/adsu.202100335

Conclusions

- A correct soiling monitoring in PV systems is essential for planning an optimum mitigation strategy.
- Estimation models can be widely used
  - Large environmental data availability in MERRA-2 and others satellite databases.
  - Subject to a site dependency, where different rates of dust accumulation are a result of a complex interaction of local environmental parameters
- Coello model might be the most suitable for urban environments
- Wrong characterization of the optical properties and of the fraction of the accumulated PM species could lead to an inappropriate estimation of the soiling losses.

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Thanks for your attention!

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