Soiling Losses – Impact on the Performance of PV Power Plants

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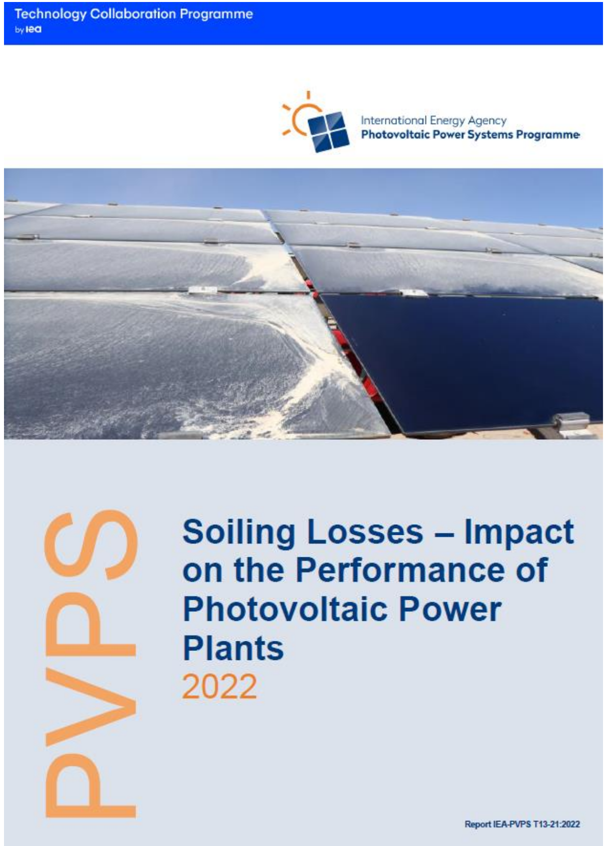
WCPEC Milano, September 26, 2022

Credits



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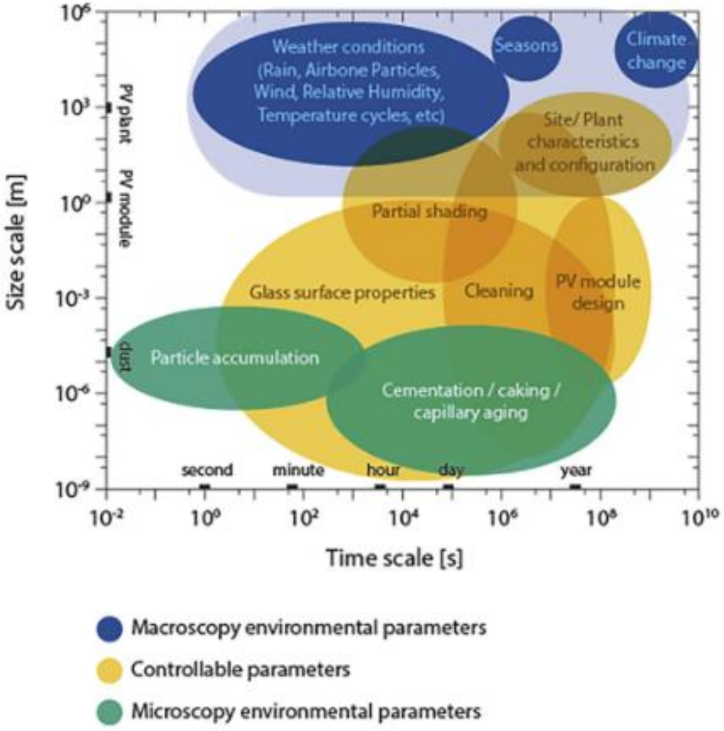
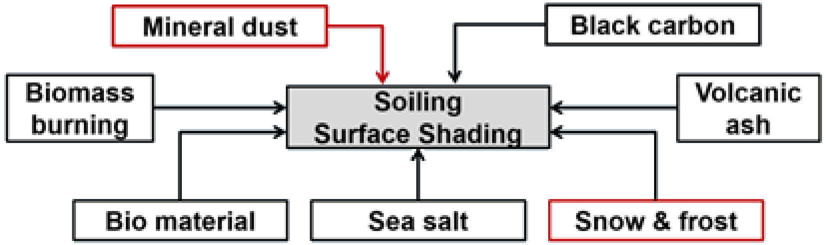
Basic physical Principles of Soiling

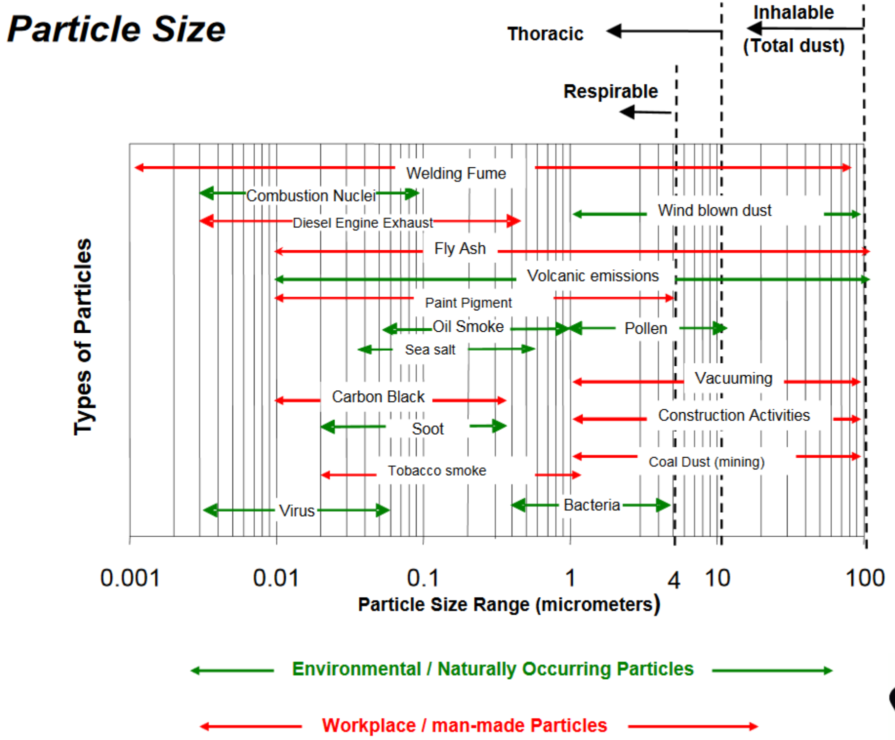


- Processes
  - Cementation
  - Caking
  - Capillary Aging

Left image: João Gabriel Bessa, Leonardo Micheli, Florencia Almonacid, Eduardo F. Fernández, Monitoring photovoltaic soiling: assessment, challenges, and perspectives of current and potential strategies, iScience,Volume 24, Issue 3, 2021, 102165, ISSN 2589-0042, (CC BY-NC-ND license); adapted from : K. Ilse, B. W. Figgis, V. Naumann, C. Hagendorf and J. Bagdahn, “Fundamentals of soiling processes on photovoltaic modules,” *Renewable & Sustainable Energy Reviews,* vol. 98, p. 239–254, 2018

Sources and Size Distribution of Particles





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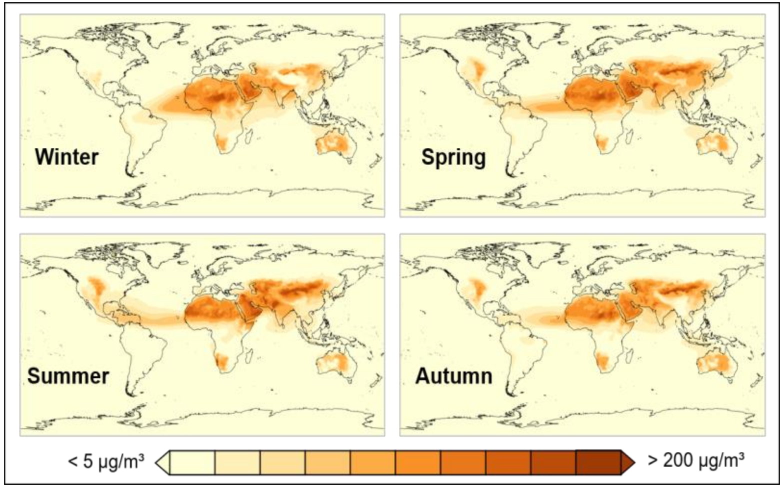
Factors influencing Soiling

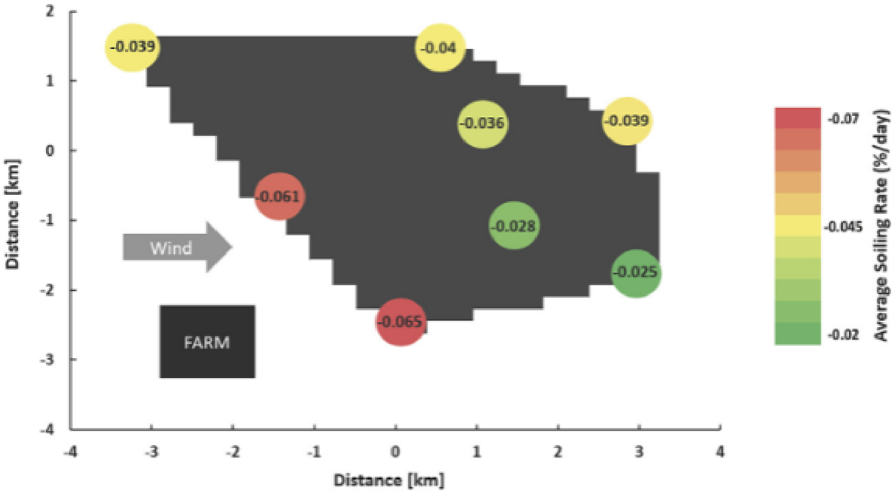
- PM concentrations
- Deposition velocities
- Wind speed and direction
- Relative humidity + dew formation
- Particle composition
- Tilt angle
- System orientation
- Local situation
- Precipitation intensity
- + inherent macroscale factors (e.g. Land use/Land Cover, NDVI, agricultural activity, prevailing soil type, etc.)

Pelland, Sophie, P. G. Pawar, Aatmaram Veeramani, William I. Gustafson and Louise Leahy Andrew Etringer. "Testing Global Models of Photovoltaic Soiling Ratios Against Field Test Data Worldwide." 2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) (A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC) (2018): 3442-3446.
Micheli, L., Muller, M., 2017. An investigation of the key parameters for predicting PV soiling losses: Key parameters for predicting PV soiling losses. Progress in Photovoltaics: Research and Applications 25, 291–307. https://doi.org/10.1002/pip.2860

Spatial and temporal variation of soiling rates



Source: kind permission by Jan Herrmann, University Freiburg



- Seasonal and intra-day variation

- Spatial variation within one plant
- Each plant is different

Right image: João Gabriel Bessa, Leonardo Micheli, Florencia Almonacid, Eduardo F. Fernández, Monitoring photovoltaic soiling: assessment, challenges, and perspectives of current and potential strategies, iScience,Volume 24, Issue 3, 2021, 102165, ISSN 2589-0042, (CC BY-NC-ND license); adapted from M. Gostein, J. R. Caron and B. Littmann, "Measuring soiling losses at utility-scale PV power plants," IEEE, 2014, p. 0885–0890.

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Inhomogeneous soiling, Sensing and IR

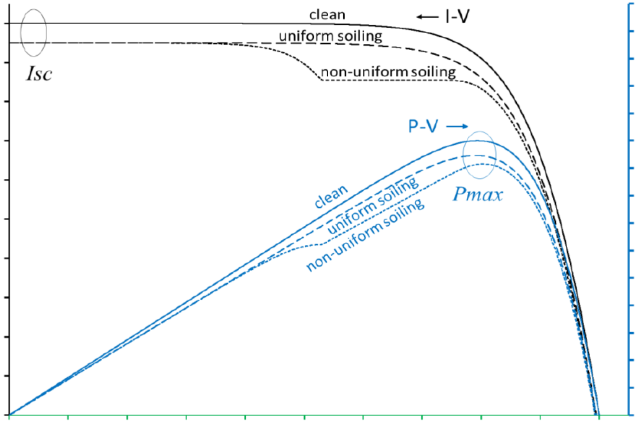
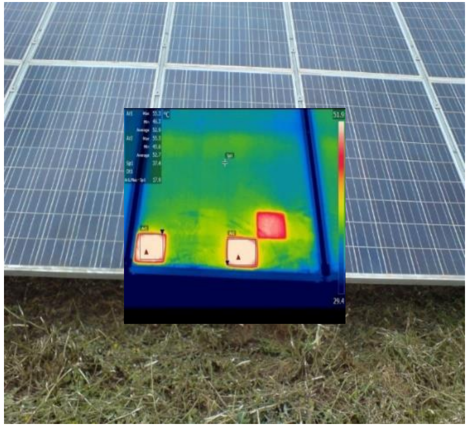


Figure 2-1: Illustration of soiled PV module and corresponding I-V & P-V curves



Commonly used metric: SRatio = Pmax_soiled / Pmax_clean

IEC 61724-1:2021 Photovoltaic system performance, Part I: Monitoring

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Image Sources: Atonometrics User Manual, D. Parlevliet, Task13; R. Zähringer, Fraunhofer ISE

Models to predict Soiling

- **Linear Regression** Models, e.g.
  - Boyle-Model (linear dependency from total suspended particle matter TSP) [3]
  - Guo-Model (dust concentration, wind speed, and relative humidity) [4]
- **Semi-Physical** models
  - Based on dust concentration and deposition models, e.g. Guo et al [4]
- **ANN** models
  - Daily delta_CI, PM10, Ta, RH, prevailing Windspeed, e.g. Javed [5]
- **Geospatial** models
  - Remote Sensing and environmental data, spatial interpolation, e.g. Micheli [6]

Mitigation of soiling losses in PVSystems

- **Preventive**
  - Site Assessment
  - Adaption and Planning
  - Anti-Soiling-Coatings
  - New Module- and Plant Concepts
- **Corrective**
  - Cleaning
    - Manual vs. fully robotic cleaning (brushes, vehicles, moving sledges etc)
    - Dry cleaning in arid regions w/o water
- cleaning practices should go into quality infrastructure for O&M (teach skilled workers)
- Best time to clean: balancing the total cost of cleaning against the cost of energy lost to soiling.

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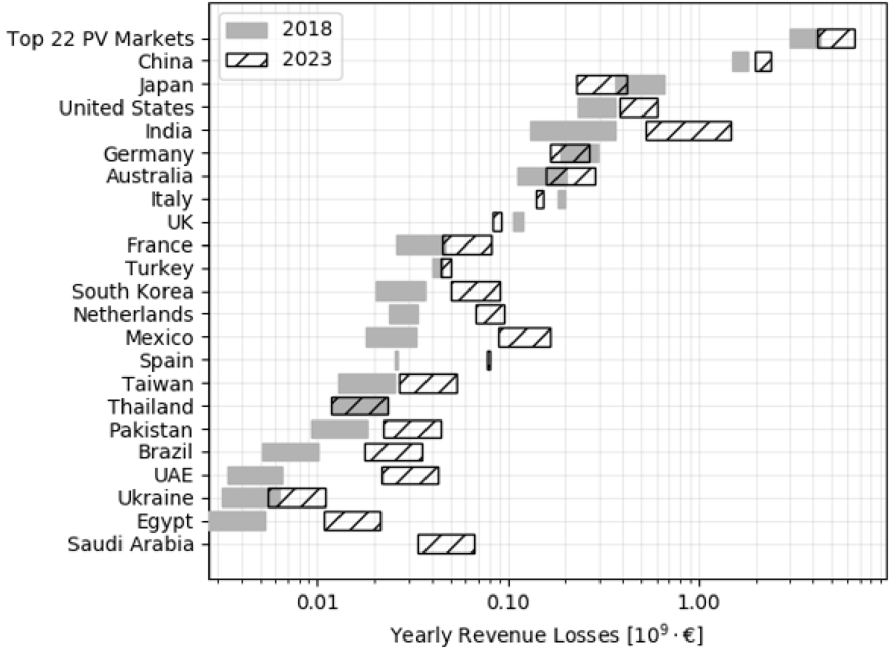
Image Source: Khadka, Nasib & Bista, Aayush & Adhikari, Binamra & Shrestha, Ashish & Bista, Diwakar & Adhikary, Brijesh. (2020). Current Practices of Solar Photovoltaic Panel Cleaning System and Future Prospects of Machine Learning Implementation. IEEE Access. PP. 1-1. 10.1109/ACCESS.2020.3011553. Licence: Creative Commons Attribution 4.0

Global economic Impact of Soiling



Estimate:

2018:

- loss ~ 3% to 4% of annual PV energy
- Economic loss ~ 3 - 5 billion €

2023:

- increase up to 4% to 5% and 4 to 7 billion €

Factors:

- Installation in high-insolation regions → Soiling
- reduced price of electricity: less revenue
- Same soiling, more efficient modules: larger energy losses

Based on optimal cleaning schedule scenario
In a real world: even higher losses

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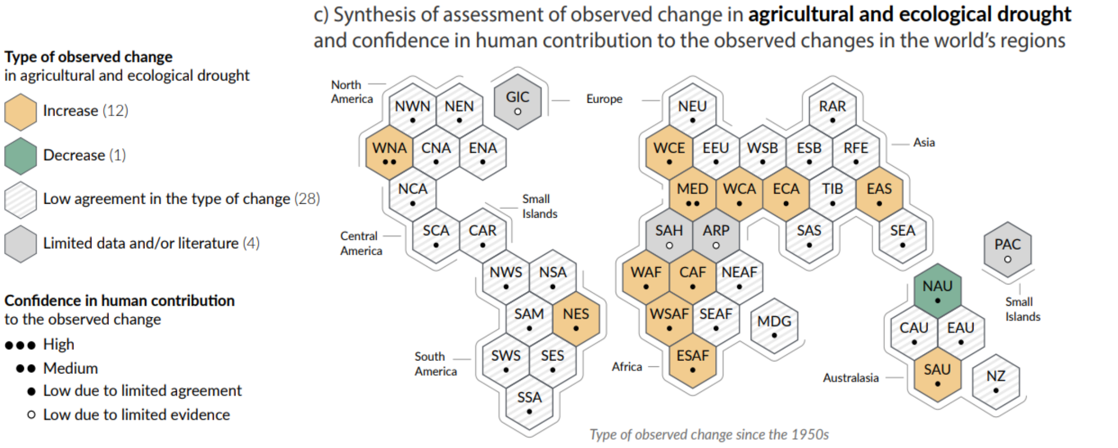
Adapted from K. Ilse, L. Micheli, B. W. Figgis, K. Lange, D. Daßler, H. Hanifi, F. Wolfertstetter, V. Naumann, C. Hagendorf, R. Gottschalg and J. Bagdahn, “Techno-Economic Assessment of Soiling Losses and Mitigation Strategies for Solar Power Generation,” *Joule,* vol. 3, no. 10, p. 2303–2321, 2019.

An outlook: IPCC projections



Each hexagon corresponds to one of the IPCC AR6 WGI reference regions

NWN *North-Western North America*

IPCC AR6 WGI reference regions: **North America: NWN** *(North-Western North America),* **NEN** *(North-Eastern North America),* **WNA** *(Western North America),* **CNA** *(Central North America),* **ENA** *(Eastern North America),* **Central America: NCA** *(Northern Central America),* **SCA** *(Southern Central America),* **CAR** *(Caribbean),* **South America: NWS** *(North-Western South America),* **NSA** *(Northern South America),* **NES** *(North-Eastern South America),* **SAM** *(South American Monsoon),* **SWS** *(South-Western South America),* **SES** *(South-Eastern South America),* **SSA** *(Southern South America),* **Europe: GIC** *(Greenland/Iceland),* **NEU** *(Northern Europe),* **WCE** *(Western and Central Europe),* **EEU** *(Eastern Europe),* **MED** *(Mediterranean),* **Africa: MED** *(Mediterranean),* **SAH** *(Sahara),* **WAF** *(Western Africa),* **CAF** *(Central Africa),* **NEAF** *(North Eastern Africa),* **SEAF** *(South Eastern Africa),* **WSAF** *(West Southern Africa),* **ESAF** *(East Southern Africa),* **MDG** *(Madagascar),* **Asia: RAR** *(Russian Arctic),* **WSB** *(West Siberia),* **ESB** *(East Siberia),* **RFE** *(Russian Far East),* **WCA** *(West Central Asia),* **ECA** *(East Central Asia),* **TIB** *(Tibetan Plateau),* **EAS** *(East Asia),* **ARP** *(Arabian Peninsula),* **SAS** *(South Asia),* **SEA** *(South East Asia),* **Australasia: NAU** *(Northern Australia),* **CAU** *(Central Australia),* **EAU** *(Eastern Australia),* **SAU** *(Southern Australia),* **NZ** *(New Zealand),* **Small Islands: CAR** *(Caribbean),* **PAC** *(Pacific Small Islands)*

Observed changes in global droughts and human contribution, IPCC report 2021:

→ Expect the problem to become worse

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Source: Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Water-field, O. Yelekçi, R. Yu and B. Zhou, Ed., Climate Change 2021 - The Physical Science Basis, Vols. IPCC, 2021: Summary for Policymakers., Cambridge University Press, p. 42.

Take home Message

- After irradiance, soiling is the **single most influential factor** on yield
- PV soiling continues to be a **global issue**, and its heterogeneity adds to O&M considerations and costs.
- A variety of **on-site monitoring** methods can inform cleaning decision timelines, esp. in heterogeneously soiled systems
- **High latitude installations** are increasing and require new approaches for snow cover.
- **Model optimization and validation** are still crucial needs for PV soiling phenomenon.

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Further References

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[TSI] https://www.tsi.com/getmedia/e3b0e7c5-1c2e-491e-8bb9-3a13205beac4/Particle_Size?ext=.pdf, accessed May 2019