Soiling of Solar Collectors

Stefan Wilbert[1*], Rone Yousif[1], Elena Ruiz[1], Peter Winkel[1], Fernanda Norde[1], Laura Campos[1], Niklas Blum[1], Natalie Hanrieder[1], Sergio Gonzalez[1], Bijan Nouri[1], Niels Algner[1], Michael Nieslony[1], Marc Röger[1], Uwe Schmitz[1], José Carballo[2], Aránzazu Fernández-García[2], Jesus Polo[2], Carmen Alonso[2], Luis Zarzalejo[2], Robert Pitz-Paal[1]

[1]DLR Institute for Solar Research, Qualification, Almería (Spain), [2]CIEMAT, PSA and Madrid (Spain), *stefan.wilbert@dlr.de

Motivation

- Soiling is responsible for a loss of 4%–7% of potential global solar energy production, despite cleaning.[1]
- Even for PV in Germany average soiling losses of about 3% are estimated.[1]

Objectives

Determine and forecast soiling levels to

- Predict solar energy yield accurately
- Optimize cleaning strategies to reach the best trade-off between the soiling losses and cleaning costs
- Identify suitable soiling mitigation measures

Soiling

Accumulation of particles + other objects (e.g. leaves, bird droppings) on solar collectors

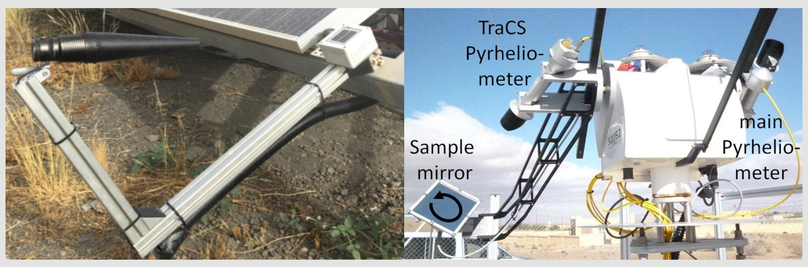
PV outdoor test bench (PVot) at CIEMAT's Plataforma Solar de Almería (PSA)

- Soiling measurement setup with pairs of different module types
- Test and develop soiling measurement and modelling methods

In-situ soiling measurements[2,3]

Development of new measurement systems:

- **Radguard PV soiling measurement**
  Comparison of irradiance signal increase caused by lamp to the signal increase after last cleaning
- **TraCS CSP soiling measurement**
  Replaces time-consuming handheld reflectometer measurements
- **T-TraCS CSP soiling measurement**
  Method for collector cover glass similar to TraCS
- **About 10 times higher soiling losses for CSP compared to PV[1]:**
  - Most forward scattered light is lost, as it is mostly not reflected towards the absorber
  - 2 passages through mirrors' soiling layer + 1 passage through soiling layer on absorber (glass cover)

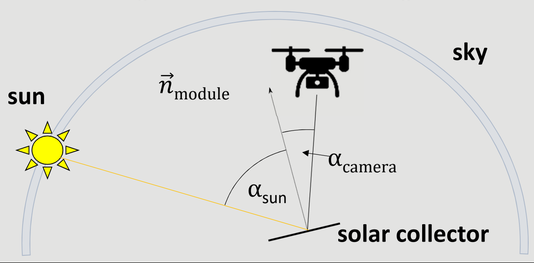


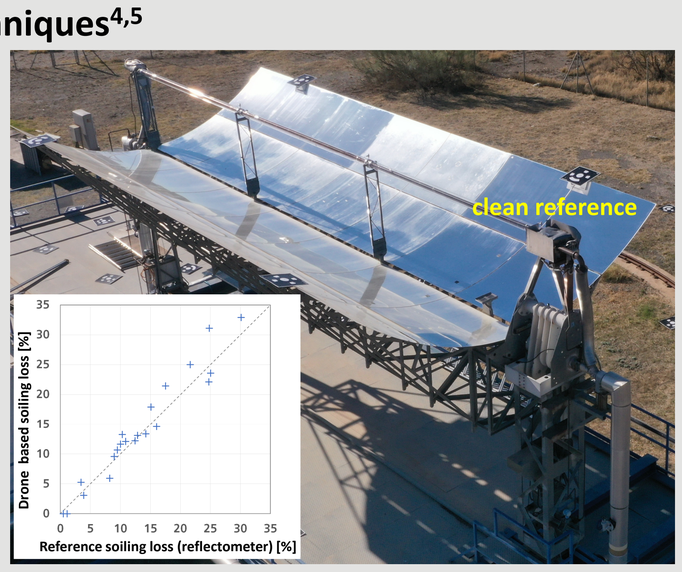
- High accuracy and acceptable maintenance effort and costs
- Tested & validated with common maintenance intense methods
- Some systems already **brought to market** (license agreements)

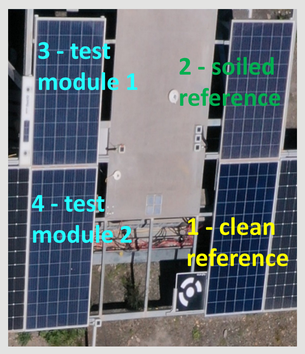
Determination of soiling loss with imaging techniques[4,5]

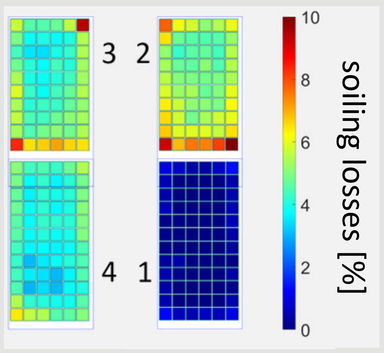
- **Method for drones and static surveillance cameras:**

1. Strong soiling e.g. by leaves is detected with AI method
2. Measure soiling effect of fine particles on collector:
   I. Particles increase the brightness of the collectors in images
   II. Use images of a clean collector to determine brightness increase for all other collectors
   III. Use images of a soiled collector with known soiling loss to convert brightness increase to soiling loss for other collectors





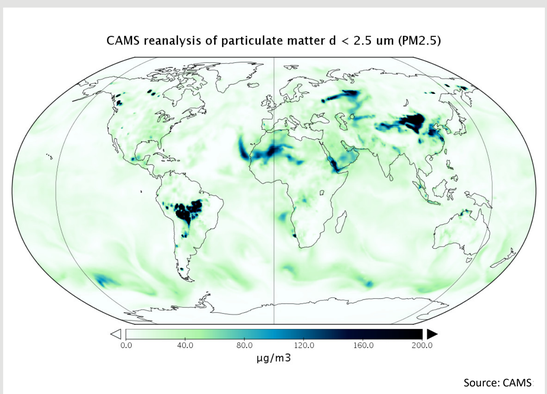


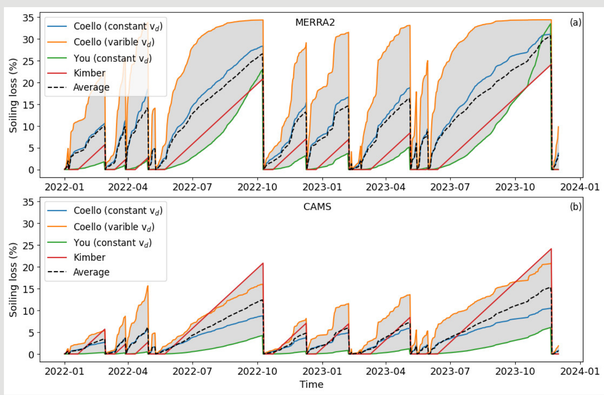


- Soiling measurement with images validated for CSP and PV
- Low deviations:
  - root mean square deviation 2.9% for CSP, 1.1% for PV
  - bias 0.3% for CSP, 0.2% for PV
- Soiling measurement for PV also relevant for degradation and other quality inspection methods (hotspots)

Soiling modelling: maps and forecasts[6,7,8]

- **Semi-physical soiling models incl. deposition and natural cleaning:**
  - Input: particulate matter, precipitation (sum and intensity), wind, collector orientation
- **Soiling maps and long-term soiling time series:**
  - Estimate the required cleaning and the expected solar yield for a given power plant site
  - Long-term time series, yearly and monthly averages
  - Based on many years of weather model reanalysis data (e.g. MERRA2, CAMS)
- **Soiling forecast**
  - Improve the cleaning schedule and production forecast during solar power plant operation
  - Probabilistic weather model forecasts of input parameters for next few days + climatology to determine the expected soiling losses for about two years



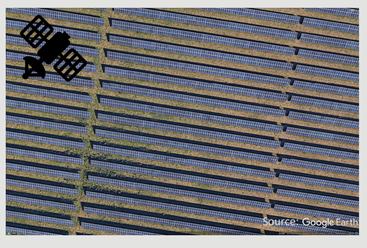


Cleaning optimization[9]

- **Cleaning recommendations from optimization software**
  - Trade-off between expected yield gain due to cleaning and maintenance costs to **increase profit**
- CSP plants and PV plants in deserts are frequently cleaned
  - Optimization of cleaning strategies with ANN → e.g. 3-day soiling-forecast can increase the profit of a CSP plant at PSA by 1.4%
- PV plants in moderate climates such as Germany are only cleaned e.g. once per year or even not at all
  - Yield increase by 1 to 3 % possible[1]

Summary and outlook

- Measurement and modelling methods for soiling losses have been developed
- Application of soiling data has been demonstrated
- Test and improve existing measurement and modelling methods and their application
- Define best practices and bring further systems to market
- Contributions to IEA PVPS and SolarPACES tasks and standards (IEC, ISO, ASTMi)
- Transfer image based soiling measurement method to smart phones and highly resolved satellite data



References

1. Ilse et al .,(2019), "Techno-economic assessment of soiling losses and mitigation strategies for solar power generation," Joule 3, 2303–2321 (2019).
2. Wolfertstetter et al., (2014), "Monitoring of Mirror and Sensor Soiling with TraCS for Improved Quality of Ground based Irradiance Measurements", Energy Procedia, Vol. 49, 2422-2432
3. Campos et al., (2022), "Autonomous measurement system for photovoltaic and radiometer soiling losses", Prog Photovolt Res Appl.2022;1–14.
4. Winkel et al. (2022). "Zell-aufgelöste Bestimmung der Verschmutzung von PV Modulen mit bildgebenden Verfahren". PV Symposium. Freiburg, 2022.
5. Wolfertstetter et al. (2019), "Airborne soiling measurements of entire solar fields with Qfly , SolarPACES conference, Daegu, South Korea.
6. Wolfertstetter et al., (2019), "Modelling the soiling rate: Dependencies on meteorological parameters", AIP Conference Proceedings 2126, 190018.
7. Norde et al. (2022), "Soiling Persistence Model as Benchmark for Soiling Forecasts of Solar Collectors", EUPVSEC conference Milan, Italy.
8. Hanrieder et al., 2021. "Why Natural Cleaning of Solar Collectors Cannot be Described Using Simple Rain Sum Thresholds". 2021 Solar World Congress Proceedings. doi:10.18086/swc.2021.37.02
9. Terhag et al., (2019), "Optimization of cleaning strategies based on ANN algorithms assessing the benefit of soiling rate forecasts", AIP Conference Proceedings 2126, 220005

Acknowledgement

Owner and operator of the Plataforma Solar de Almería is the Spanish research center CIEMAT. We thank the EC for funding the WASCOP (Grant Agreement number: 654479) and SOLWARIS (792103) projects and the German Federal Ministry for Economic Affairs and Climate Action for funding the AUDROMON (03EE5128A), LEIA (03EE5134A) and PVOptDigital (03EE1107B) projects.

European Union

Federal Ministry for Economic Affairs and Climate Action

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

DLR