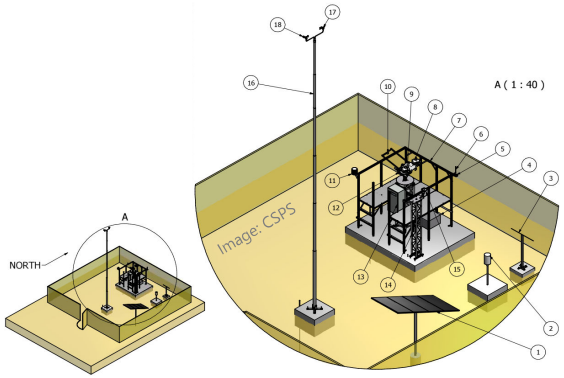


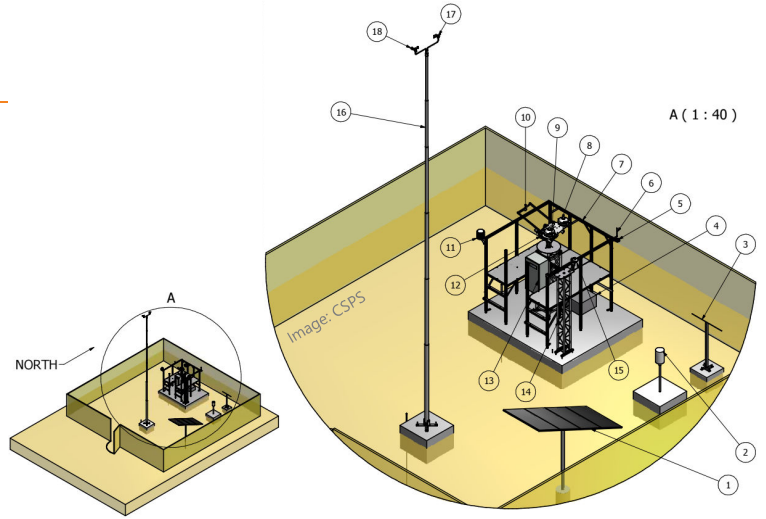
Measuring Solar Radiation / Further Relevant Meteorological Parameters

Stefan Wilbert, Thomas Stoffel, Daryl Myers, Stephen Wilcox, Aron Habte, Frank Vignola, Anton Driesse, Vicente Lara-Fanego, Nicholas Riedel-Lyngskær, Josh Peterson, Robert Höller, Birk Kraas, Anne Forstinger, Natalie Hanrieder, Manajit Sengupta, Yu Xie, Tomas Landelius, Jesús Polo, Christian Gueymard

EUPVSEC, Vienna, 25.9.24

Table of contents

- Measuring Solar Radiation
  - Chapter 3



- Further Relevant Meteorological Parameters
  - Wind, temperature, …, soiling
  - Ground measurement and models
  - Chapter 5

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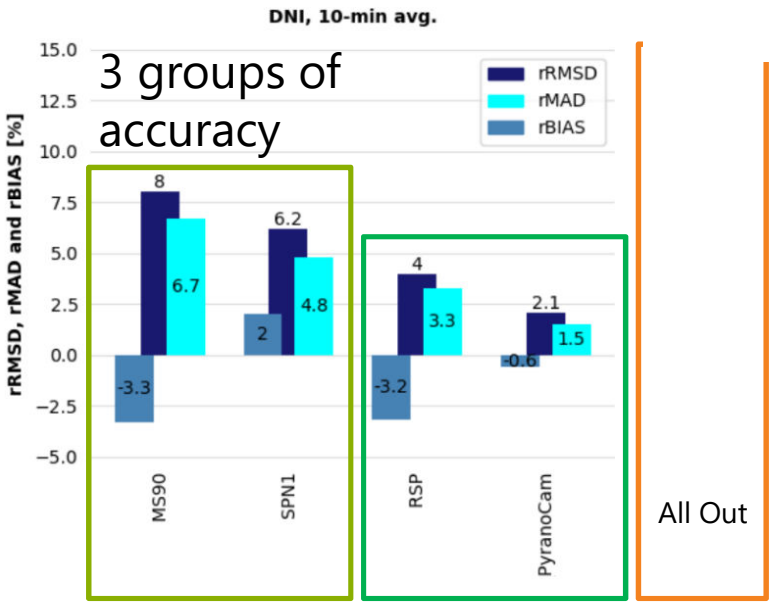
Measuring solar radiation (Chapter 3) - overview

- Radiometer types
  - Description, characteristics, calibration, classification, systematic errors
  - **Simple sensors for DHI (diffuse horizontal irradiance) or DNI (direct normal irradiance)**
- **Albedo and rear plane-of-array irradiance (RPOA) measurement**
- **Recommended radiation measurement parameters/instruments per project phase**
- Measurement station design & operations
  - **Exemplary station plans and checklists for installation and maintenance**

Simple sensors for DHI or DNI measurement

- Simple = without solar tracker
- Especially relevant for bifacial PV to derive RPOA from albedo, GHI & DHI or DNI
- System description, new benchmark

Images by DLR at CIEMAT's Plataforma Solar de Almería.



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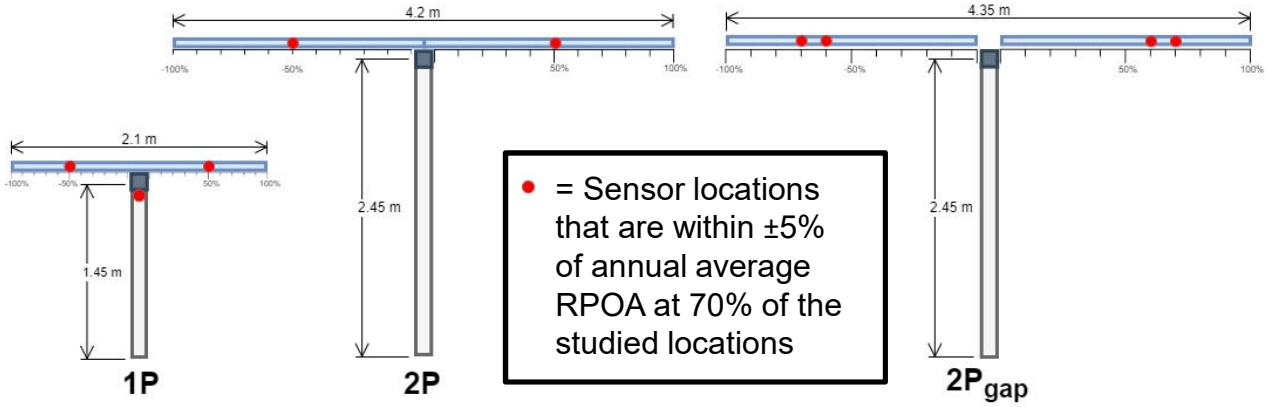
Albedo and RPOA measurement

- Examples for deviation of annual energy production for erroneous albedo
  - 0.10 albedo error (e.g. due to variable ground type sand/dry grass) -> 2.5% production error for example PV
- Albedo measurement recommendations:
  - heights 1.5 to 2m / ≥5m radius below without objects / sort out for shadows
- RPOA measurement recommendations for different mounting types

Image by University of Applied Sciences of Upper Austria



Images by Nicholas Riedel-Lyngskær

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Radiation measurement parameters / instruments per project phase

* for large installations (>50 MW); ** for fixed-tilt PV at high latitudes

Project Phase/ Standards	Accuracy Case	Monofacial PV, Thermal Non-Concentrating	BPV	Concentrating Technology
Before Construction of Large Solar Plants (based on IEC TS 62862-1-2)	Basic	GHI	GHI, RHI (albedo), DHI	GHI, and DNI or DHI
	Enhanced (large plants; complex atmosphere, terrain, technology)	GHI, GTI/PV matched GTI (in the plane(s) that has/have been selected as promising option(s) or tracked), DNI*, DHI*, RHI (albedo)**	GHI, DNI, DHI, RHI (albedo), GTI or PV-matched GTI (in the plane(s) that has/have been selected as promising option(s) or tracked)	DNI, GHI, DHI
Monitoring and Operation for Large and Medium Solar Plants (for PV: IEC 61724-1; for CST: IEC 62862-3-2, IEC 62862-5-2, IEC 62862-3-3; for thermal collectors: ISO 9806)	Basic	GHI GTI or PV-matched GTI	GHI, GTI or PV-matched GTI, RPOA (spectrally matched or broadband) or RHI (albedo)+DHI	DNI or DHI and GHI for medium plants
	Enhanced	GHI, GTI, PV-matched GTI, DNI*, DHI*, RHI (albedo)**	GHI, GTI, PV-matched GTI, RPOA (spectrally matched or broadband), RHI (albedo), DHI, DNI*	DNI GHI DHI

Measurement station design & operations

- Exemplary station plans and checklists for installation and maintenance

Component	Work Item	Checked		Comments
		Yes	No	
North-south line	The station's north-south line established and clearly marked prior to construction.	X		
Foundations, fence	Foundations correctly prepared	X		
	Threaded bolts correctly prepared	X		
	Fence correctly prepared	X		
	Project signs attached	X		
Support structure with control box	PV mounting supports adjusted	X		
	Horizontally leveled	X		
Wiring, cables	Visual examination	X		
	Fuses okay	X		
	All sensors connected	X		
	All cables orderly fixed	X		
Solar tracker	Shading assembly installed	X		
	Horizontal leveling	X		
	East/	X		

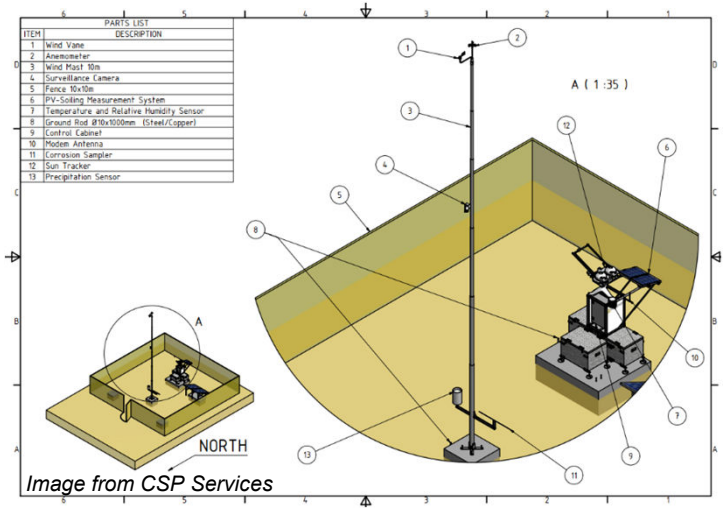

Image from CSP Services

Needed Picture	Received
Fence and foundation with north reference	X
Station and wind mast foundations	X
Wind mast preparations/setup	X
Wind mast foundations ground cable	X

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Further relevant meteorological parameters

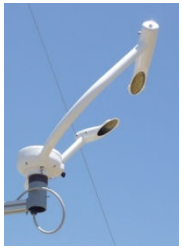
Windspeed, direction, and gust

Precipitation

Temperature, humidity, pressure

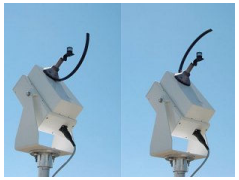
Albedo

Soiling



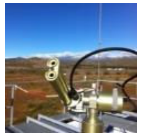
Attenuation between heliostat and receiver of tower plants

UV irradiance



Circumsolar irradiance

Photo-synthetically active radiation



Aerosols and water vapor

Spectral irradiance

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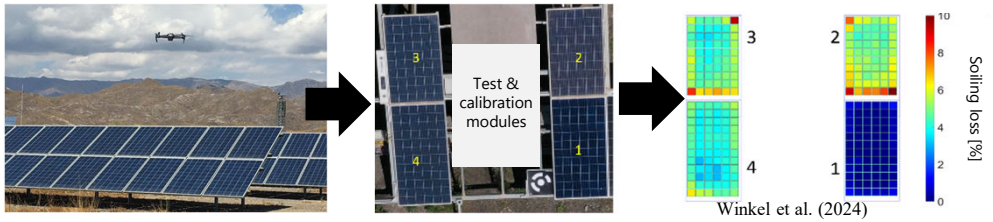
Images by DLR at CIEMAT's Plataforma Solar de Almería & by University of Applied Sciences of Upper Austria.

-Definitions
-Effects on solar energy
-Measurement options
-Modelled data sources
-References

Soiling

- Strongly relevant parameter for all solar energy technologies
  - Even in central Europe, observed PV soiling loss can be >50% & avg. loss ≈3%
  - Application: yield estimation, cleaning optimization, separate the soiling issue from other technical problems
- Various soiling measurements options
  - Point-like and spatially resolved data
- Soiling models: deposition, natural cleaning, soiling maps
- Some recommendations for data evaluation & maintenance of soiling sensors
- Link to PVPS T13 soiling report



Winkel et al. (2024)

Images by DLR at CIEMAT's Plataforma Solar de Almería.

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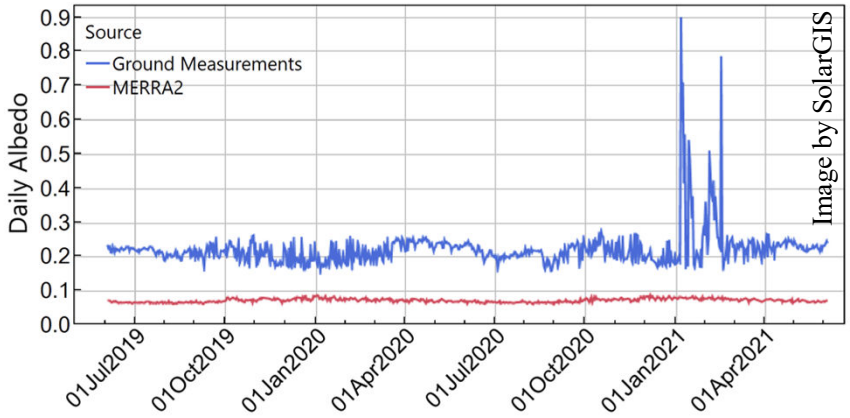
Albedo

- Albedo measurements are not the only important data source
- Several satellite and reanalysis data sets (-> Gueymard et al. 2019, summary)
  - Different temporal and spatial resolutions, different errors
  - Coarser resolution typically less accurate (exception CMSAF)
  - Including MODIS observations helps

Example for errors MERRA2 data: pixel that includes the station also includes a large fraction of water -> ~3% BPV underestimation



Tested Dataset	Source	Time Resolution	Spatial Resolution
CMSAF	Satellite, CLARA-A2-SAL	5 d	25 km
GLASS	Satellite, AVHRR	8 d	5.6 km
MCD43A3	Satellite, MODIS	1 d	5.6 km
Mines ParisTech	Satellite, MODIS	Monthly mean (2004–2011)	≈5.6 km
NSRDB	Satellite, MODIS	1 d	4 km
SGClim	Satellite, MODIS, and Solargis method	Monthly mean (2006–2015)	1 km
ERA5	ECMWF, reanalysis	1 h	≈30 km
MERRA2	NASA, reanalysis	1 h	≈55 km

Lara-Fanego et al. (2022a)

Parameters relevant for agrivoltaics

- Additional radiation parameters required for the crops (microclimate)
- Importance of some meteo parameters is enhanced in the case of agrivoltaics
- Link to WMO *Guide to Agricultural Meteorological Practices*
- So far mainly definitions and sensors, e.g.:
  - Photosynthetically active radiation (PAR)
    - Irradiance of PAR [W/m²]
    - Photosynthetic photon flux density (PPFD) [µmol/(m^2·s)]
  - Daily light integral (DLI) [mol/(m^2·day)]
  - Light quality for plant growth: red/far-red ratio

APV experiment in a greenhouse of Fundación UAL-Anecoop.

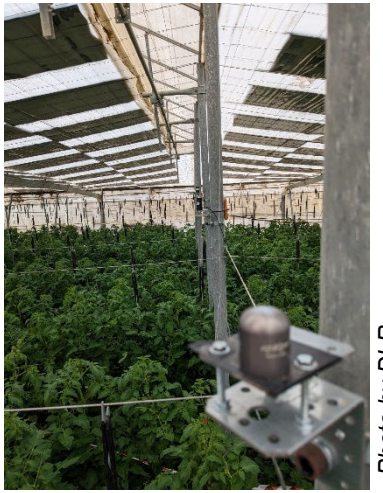
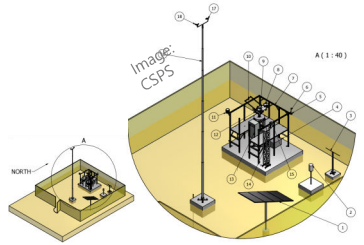


Photo by DLR

Summary / Outlook



- Some bigger updates in chapters 3 and 5
  - “Measuring Solar Radiation”
    - Simple sensors for DHI or DNI
    - Albedo and RPOA measurement
    - Necessary radiation measurement parameters/instruments per project phase
    - Exemplary station plans and checklists for installation and maintenance
  - “Further Relevant Meteorological Parameters”
    - Soiling
    - Albedo
    - Agrivoltaics

- Next updates partly identified, e.g. more recommendations on albedo data, APV

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Measuring Solar Radiation

- Simple sensors for DHI or DNI
- Albedo and RPOA measurement
- Radiation measurement parameters/instruments per project phase
- Exemplary station plans and checklists for installation and maintenance

/ Further Relevant Meteorological Parameters

- Soiling
- Albedo data sets
- Parameters for agrivoltaics

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Thank you!

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on the basis of a decision by the German Bundestag