Quantifying the Impact of Dust and Snow on PV Power Plants

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IEA PVPS

Technology Collaboration Programme
by iea

Different types of soiling

Dust

Snow

Pollen

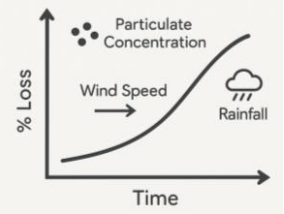
Agriculture

Birds

PVPS

PVRADAR

Main Types of Dust Soiling Models

	Fixed rate models	Particle deposition models
		
General idea	**Soiling accumulates at a constant rate.**	**Soiling accumulates based on environmental conditions.**
Inputs	• constant rate • rainfall	• particle concentration (PM2.5, PM10, etc.) • wind, temperature, humidity … • tilt angle
Parameters	• rain cleaning threshold	• rain cleaning threshold & efficiency • dust deposition velocities + many more depending on model
Examples	Kimber model	Coello model / HSU, You, Bergin PVRADAR, …

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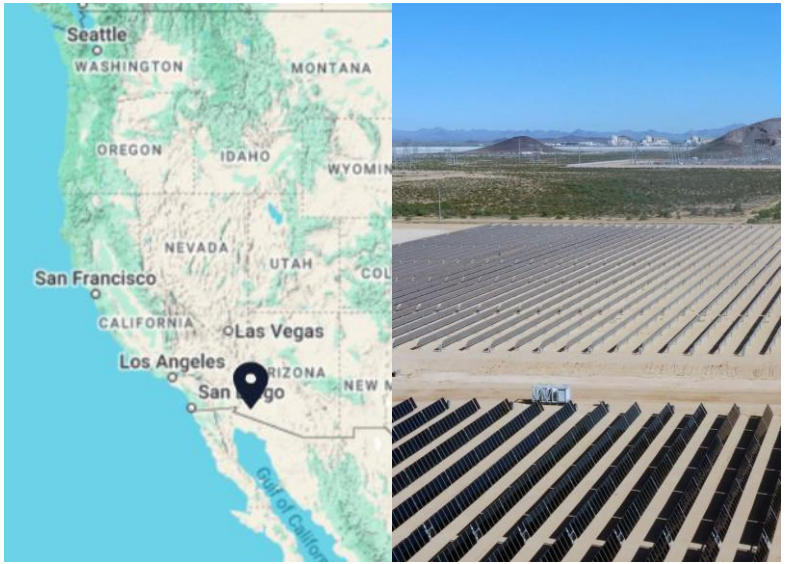
Let’s look at an example:



New development project near Yuma, Arizona.

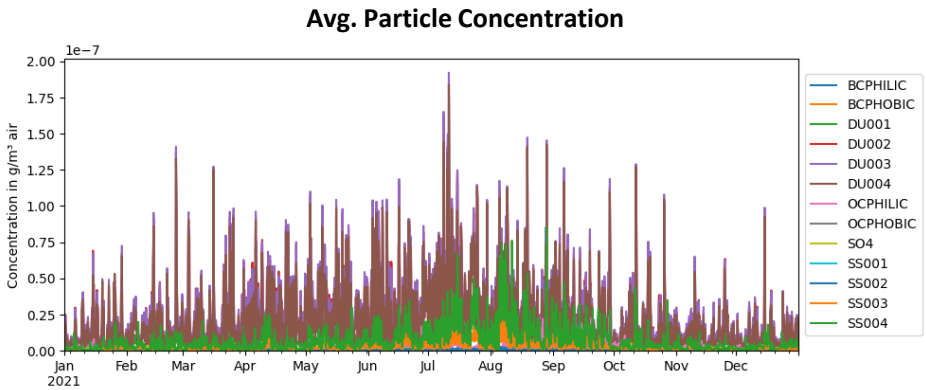
1. **How to get average monthly soiling loss factors?**
2. **How to determine optimal cleaning frequency?**

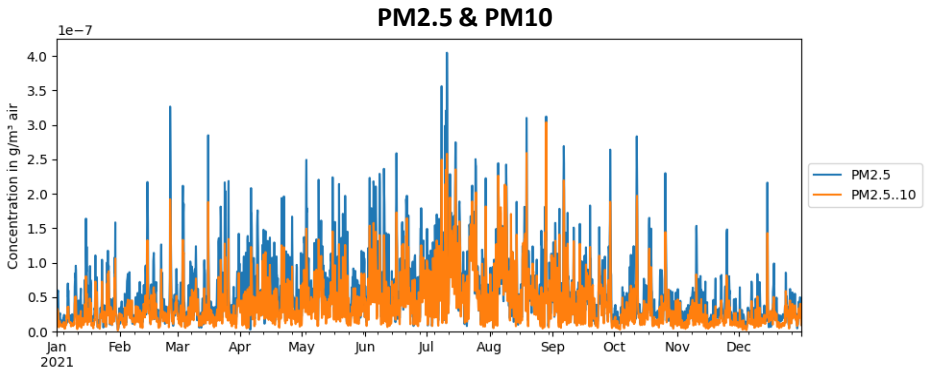
Particle Concentration

Physical Soiling model

Particle concentration

Energy & Cost





Modern-Era Retrospective analysis for Research and Applications (MERRA-2)

- MERRA2 offers concentration of a variety of particles
- Can be grouped by diameter to produce PM2.5 & PM10
- Other sources of soiling: snow, pollen, agriculture, industry ...

Historic Rain Patterns

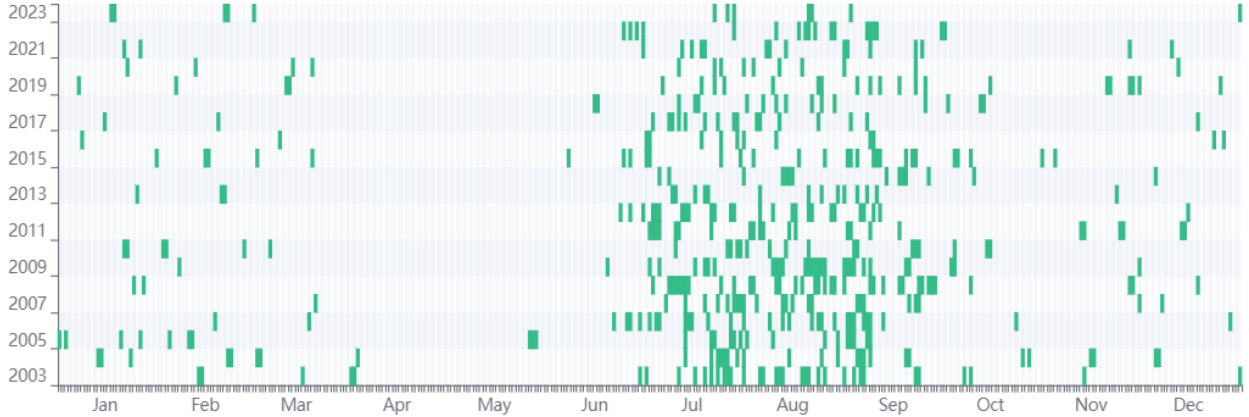
Physical Soiling model

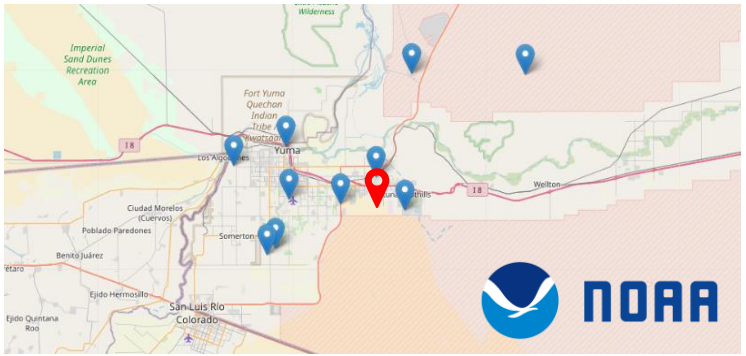
Particle concentration

Rain

Energy & Cost

Heatmap showing all registered rain events for the past years





If available, always use data from nearby weather stations.

Soiling Level & Rain Cleaning

Physical Soiling model

Particle concentration

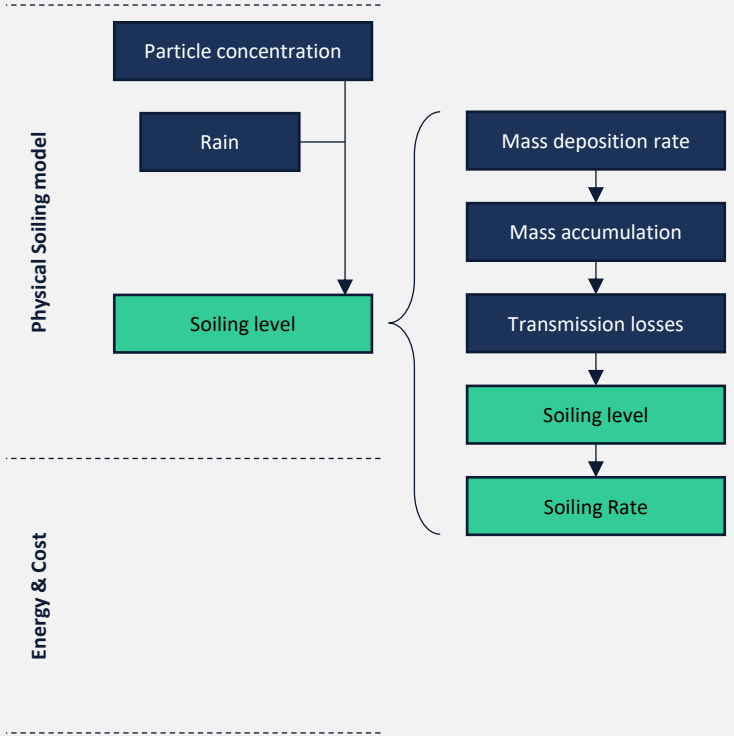
Rain

Soiling level

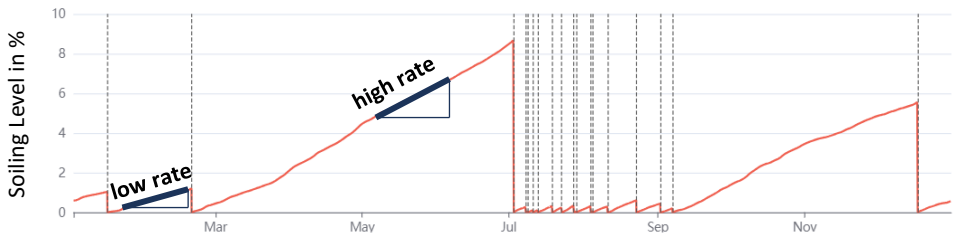
Energy & Cost

Heatmap showing all registered rain events for the past years

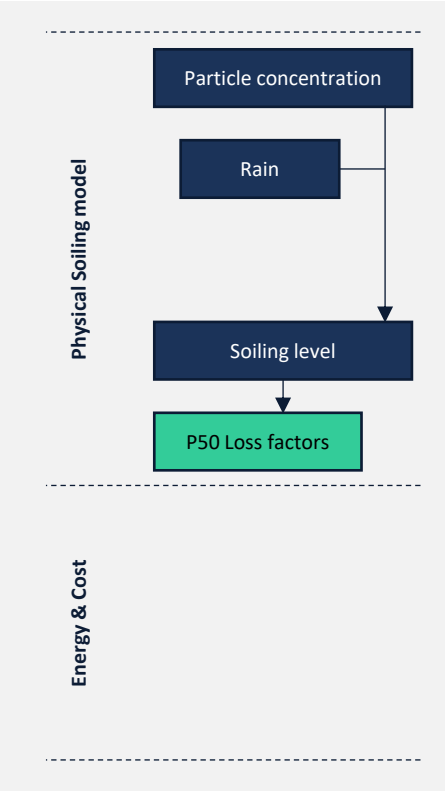
Soiling Accumulation

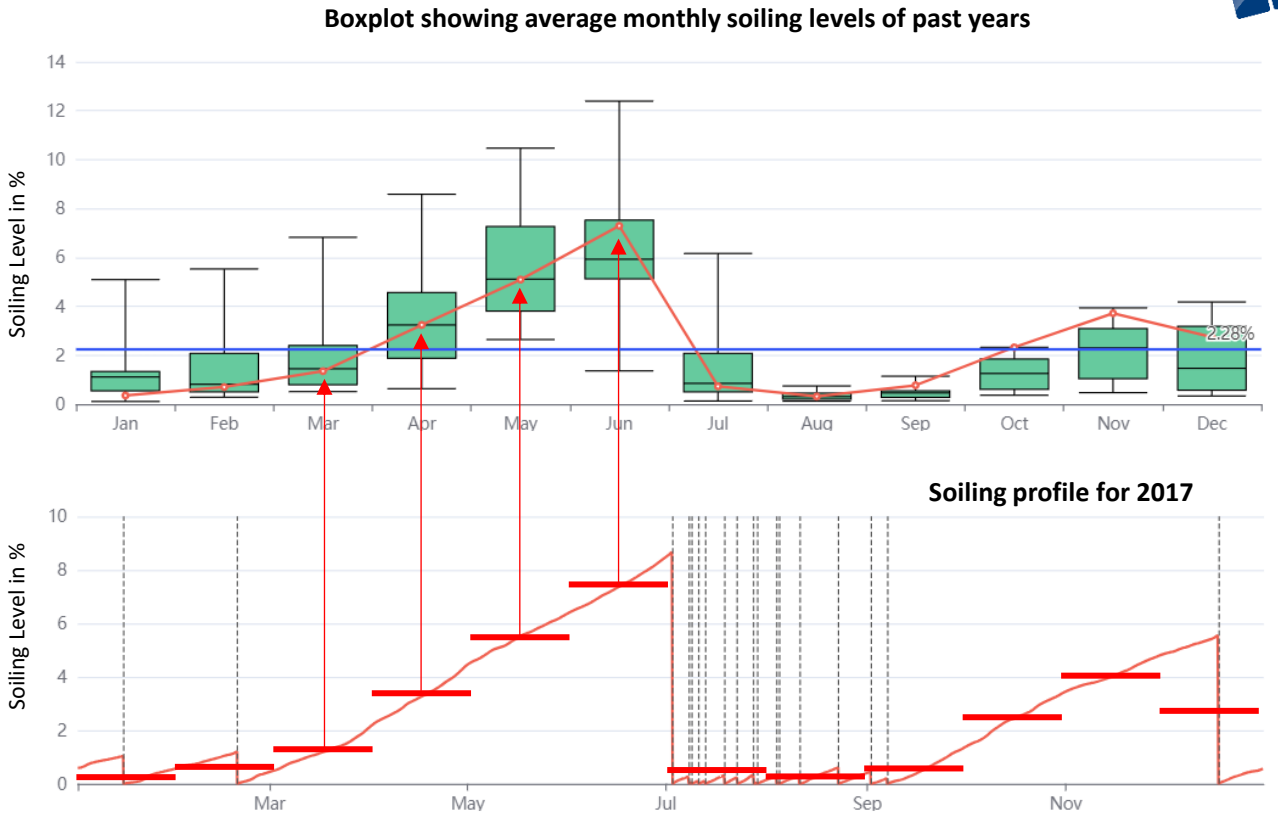


- Particles deposit on the (front) surface of PV modules
- Particles accumulate on the glass surface
- Particles shade part of the incoming irradiation

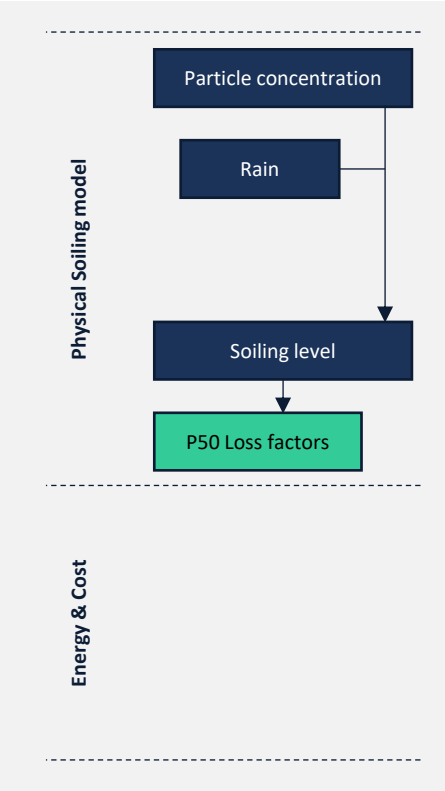


P50 Soiling Loss Factors

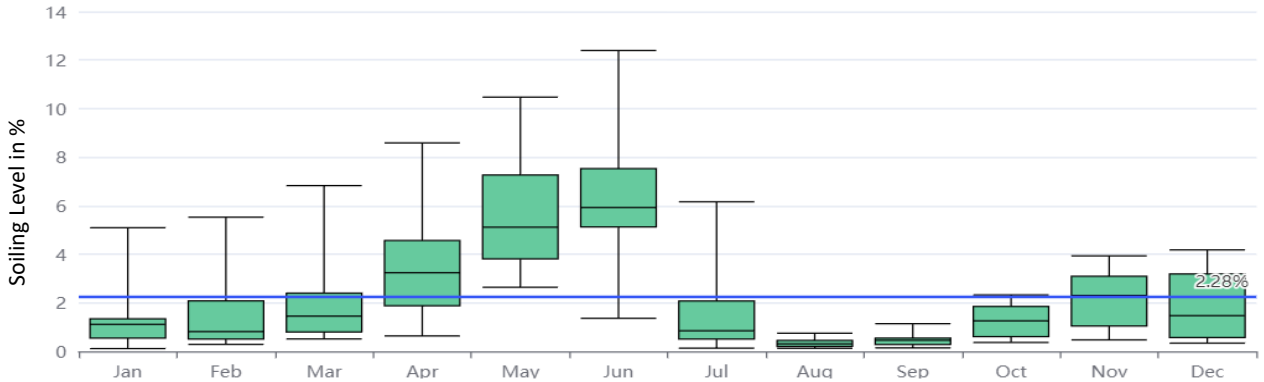




P50 Soiling Loss Factors



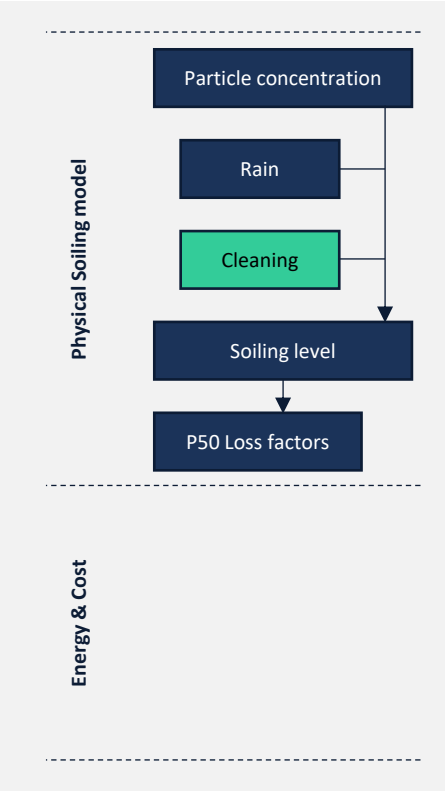
Boxplot showing average monthly soiling levels of past years

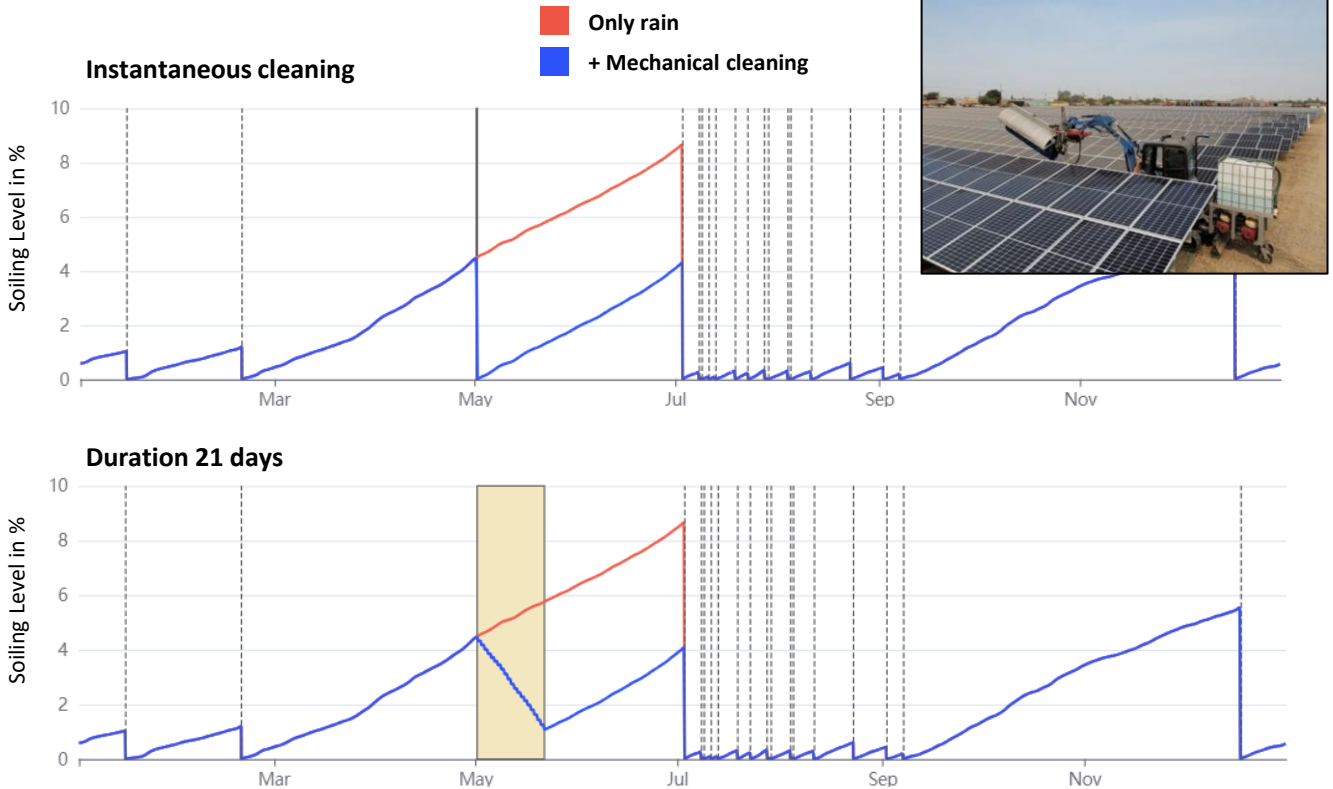


P50, P90 & P99 Monthly Soiling Loss Factors

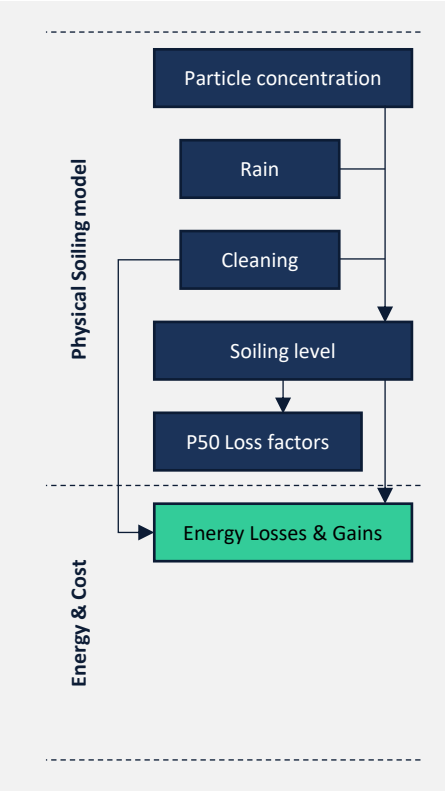
Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P50	1.111	0.8147	1.448	3.239	5.112	5.925	0.8483	0.3075	0.4555	1.257	2.302	1.467
P90	2.381	3.285	4.508	6.616	8.566	8.881	2.578	0.5601	0.6738	2.052	3.717	3.419
P99	5.091	5.526	6.824	8.586	10.47	12.39	6.16	0.744	1.139	2.324	3.934	4.177

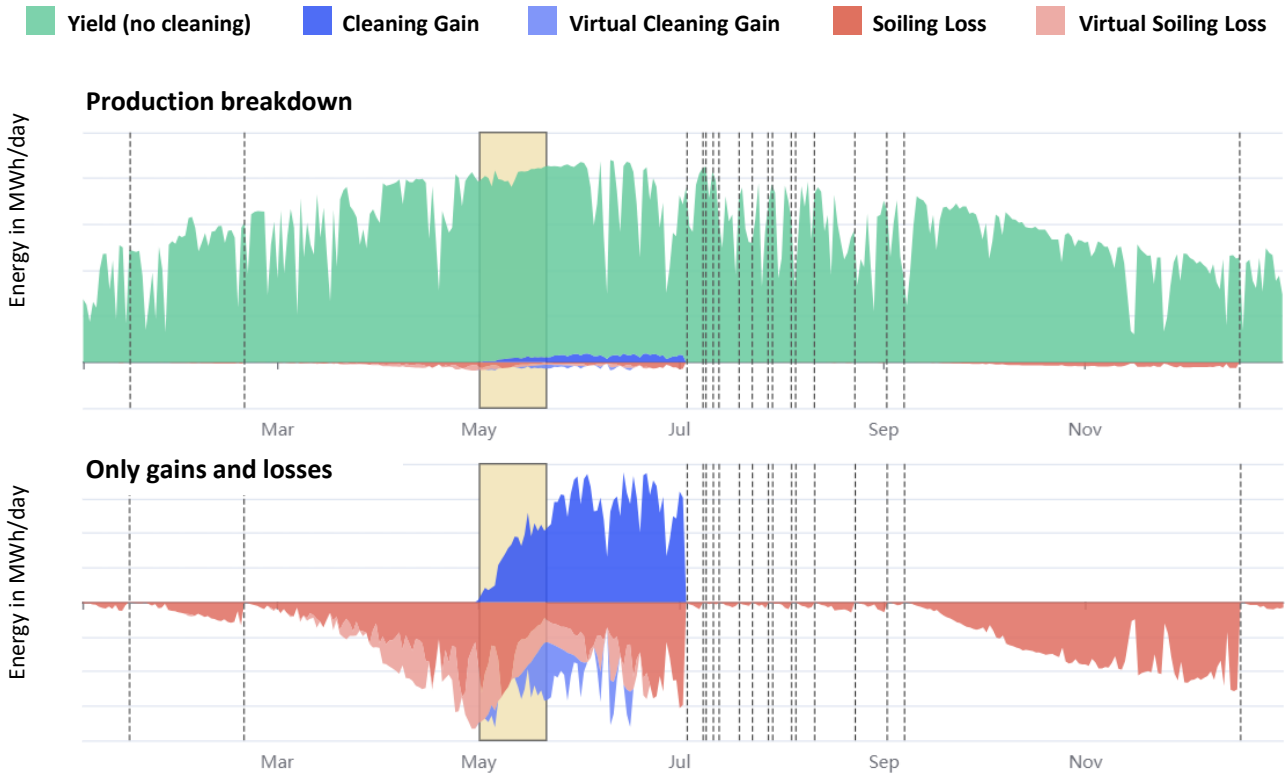
Mechanical cleaning





Energy Losses & Gains





Modelling of Cleaning Alternatives

Manual Cleaning

Fully-autonomous robot

Tractor + Brush (dry / wet)

Semi autonomous robot

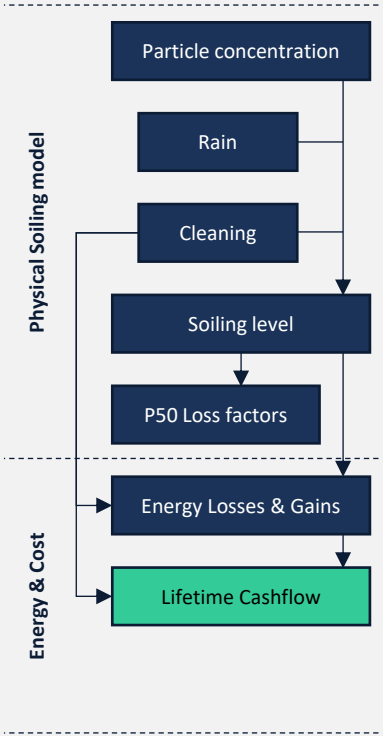
Technical parameters

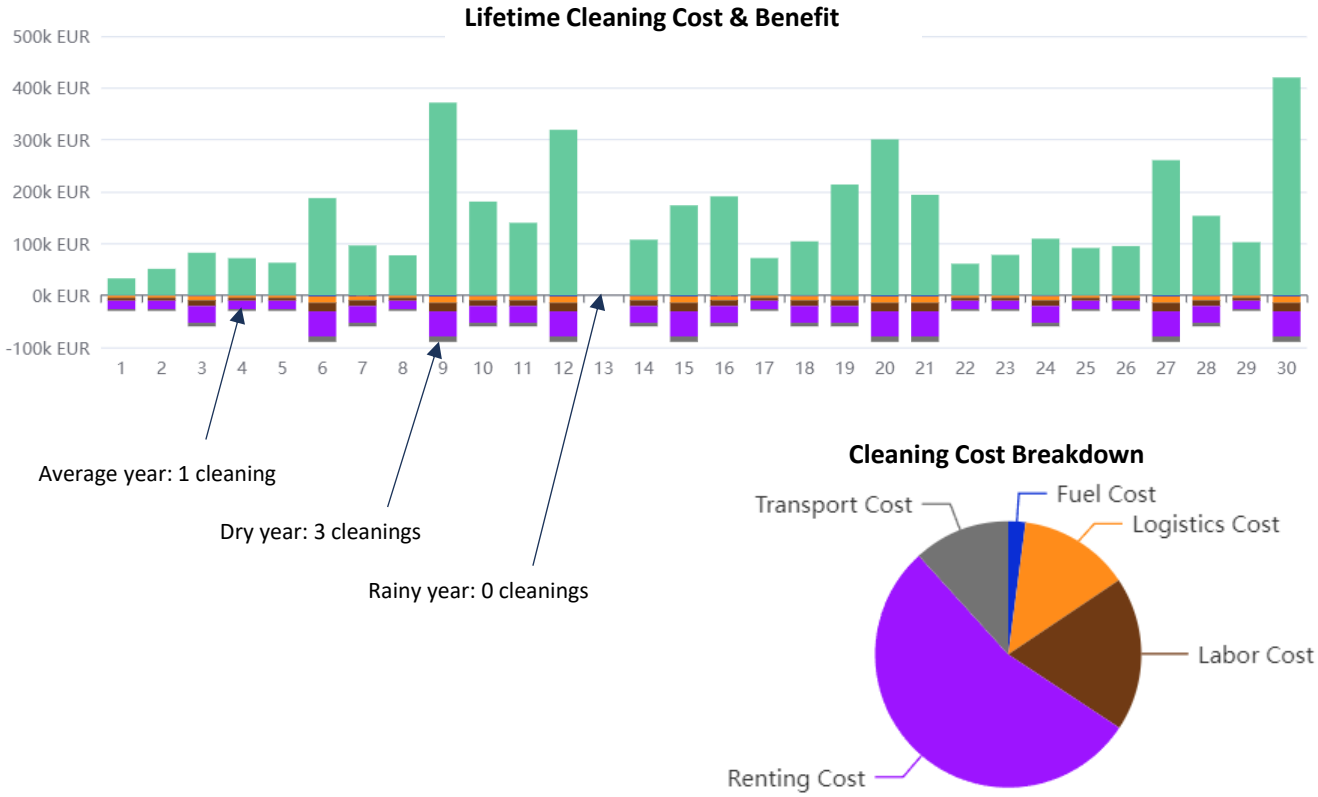
- Cleaning speed
- Water & Fuel consumption
- Personnel needed
- Component lifetimes
- …

Economic parameters

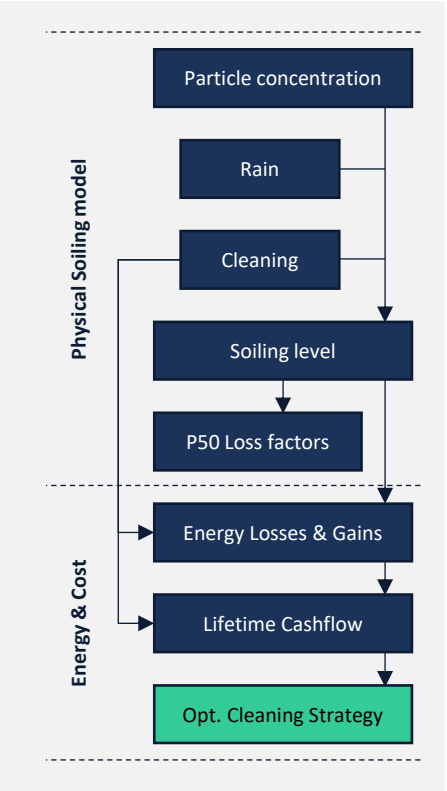
- Business model: purchase or service
- Purchase and replacement cost
- Commodity cost
- Labor rate
- Service fees
- …

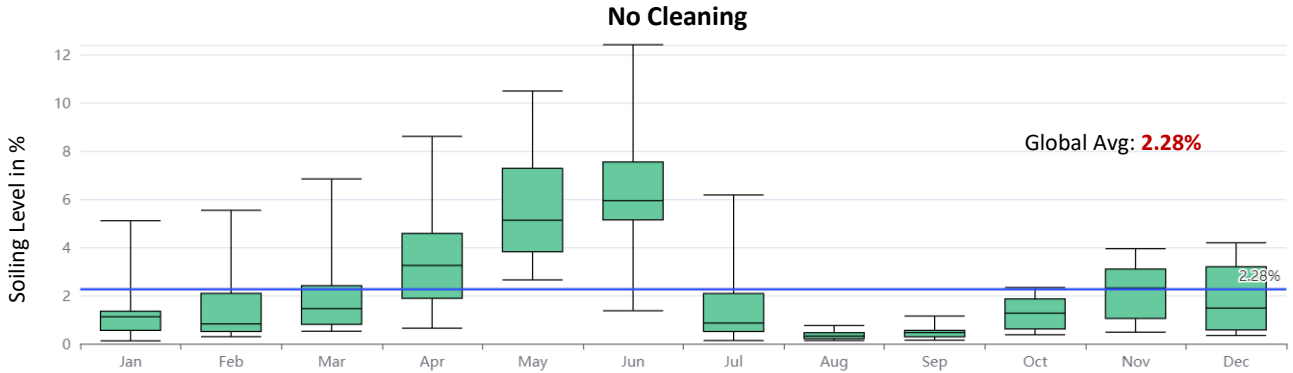
Optimal Cleaning Strategy

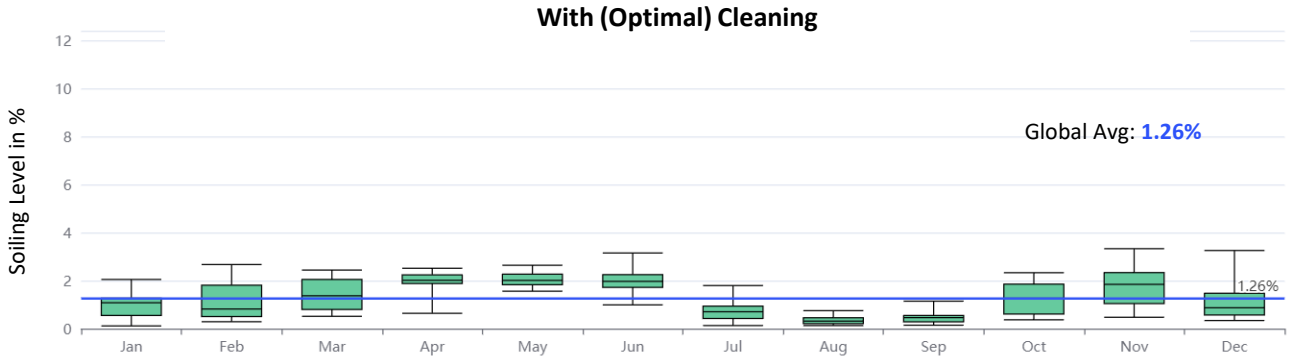




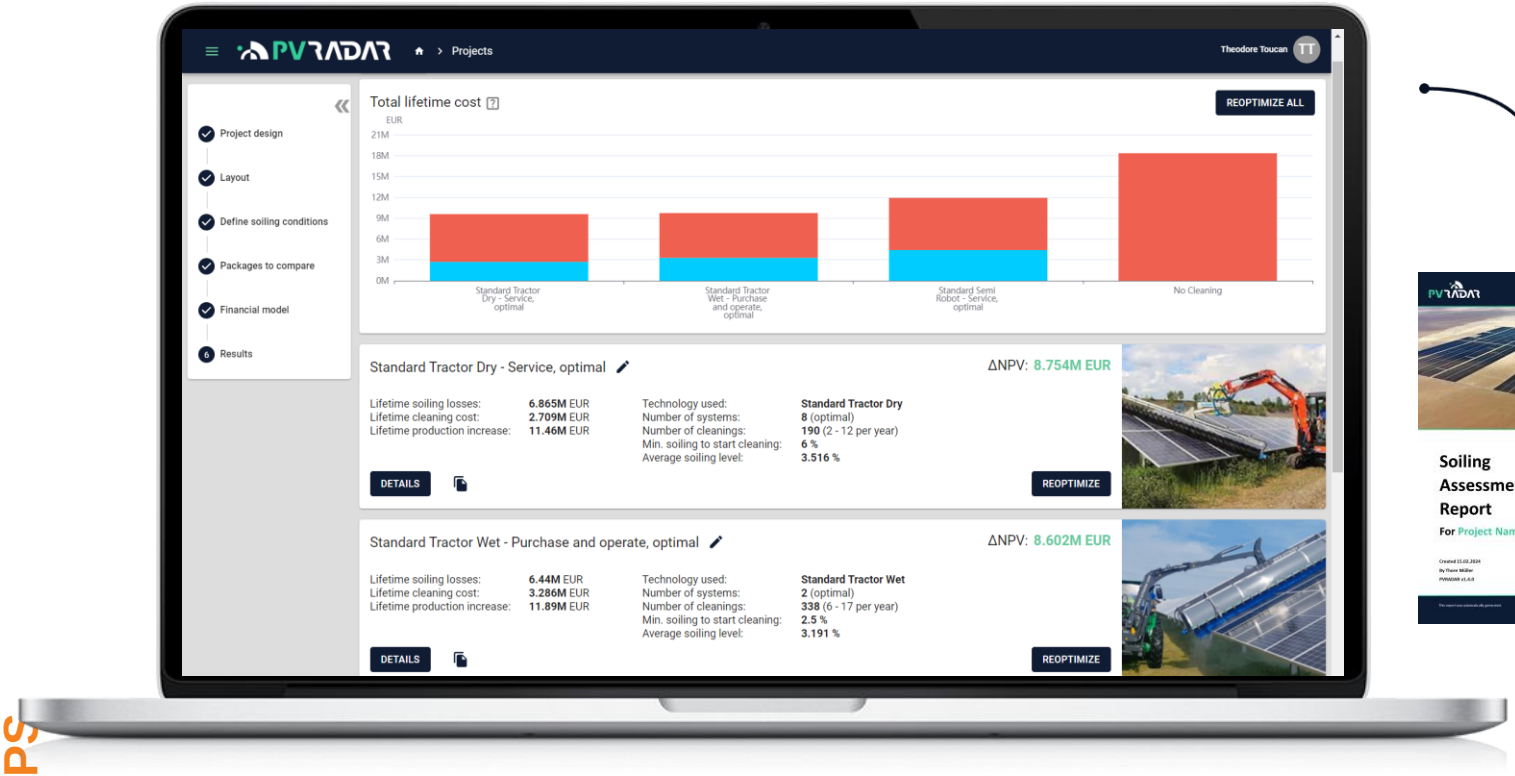
Avg. Monthly Losses w and w/o Cleaning





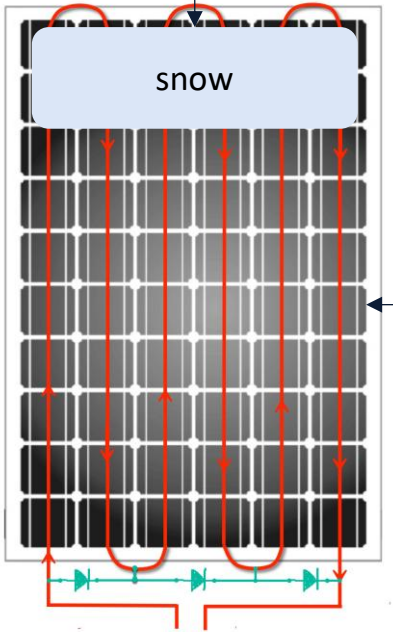


Lifetime cost comparison of different cleaning strategies



Snow Soiling

Types of Snow Losses

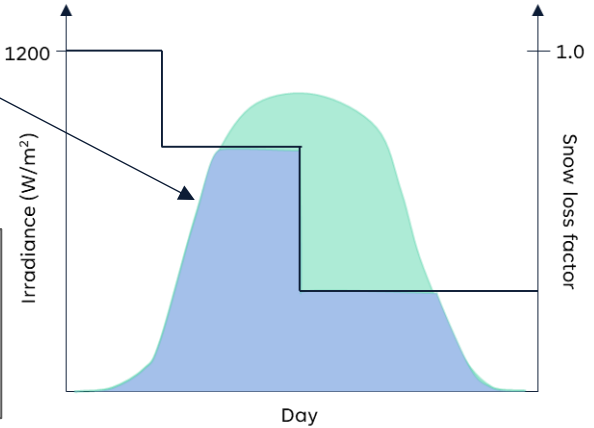


Snow coverage:
The fraction of the module surface covered by snow.

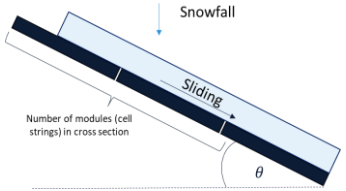
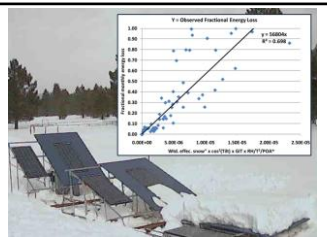
Snow loss factor
The fraction of the DC power lost due to snow.

Snow energy loss:
The energy output lost due to snow

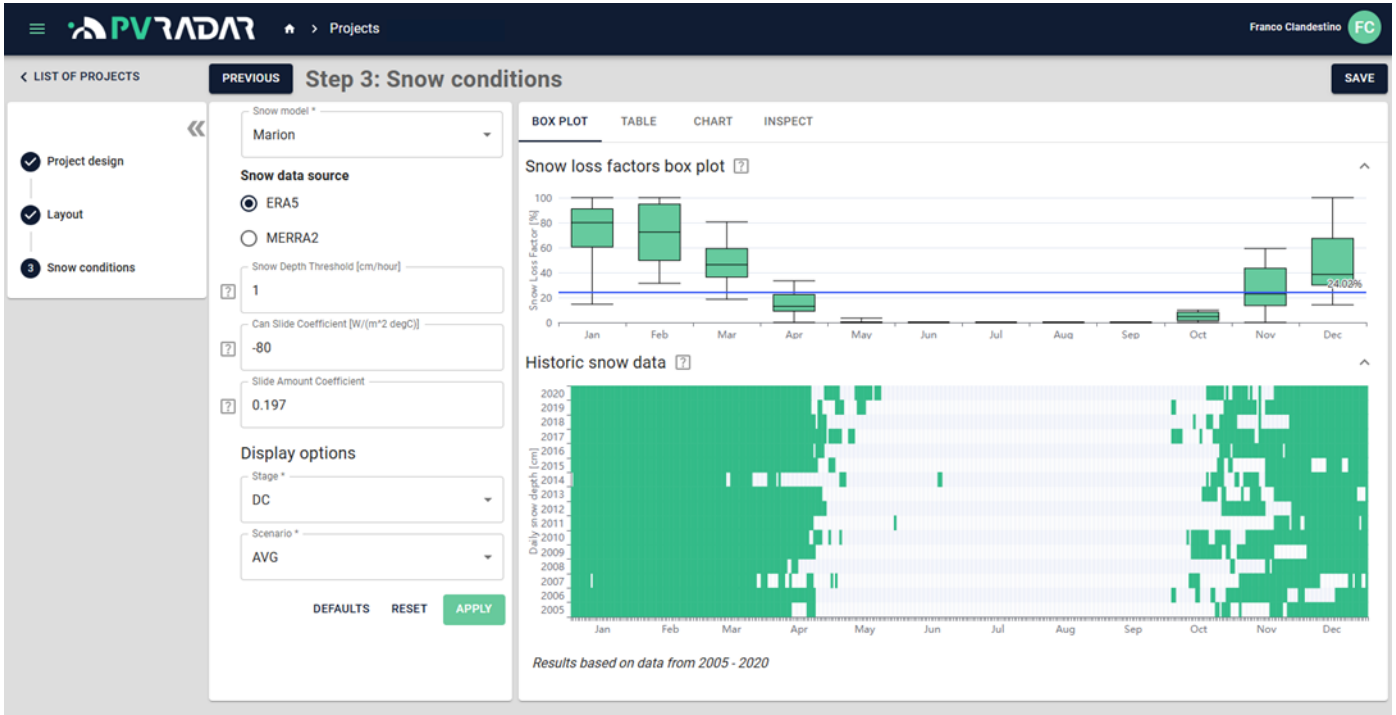
Snow energy loss fraction:
The ratio of the energy lost (green) and total hypothetical energy (green + blue).



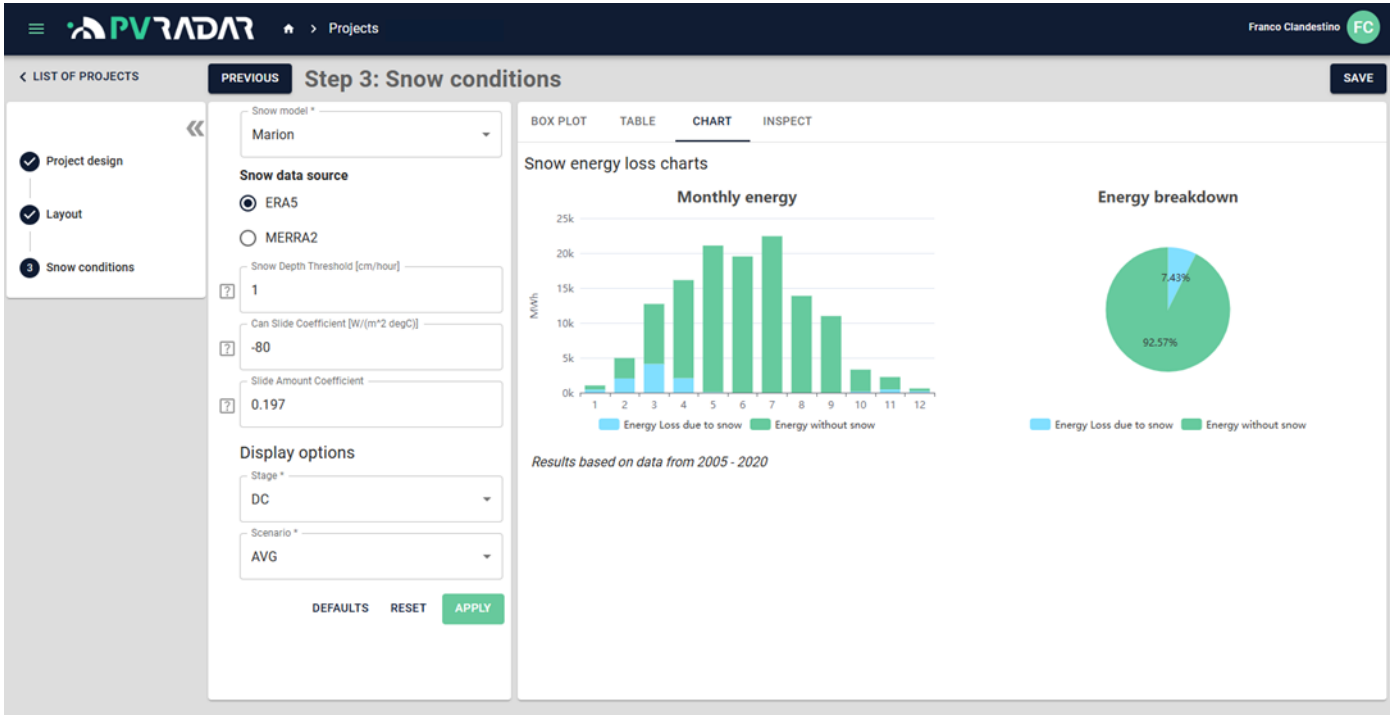
Popular Snow Loss Models

	Marion	Townsend
		
General idea	Snow accumulates and slides off	Empirical model
Inputs	• Snowfall (hourly) • Tamb (hourly) • POA (hourly) • Array geometry	• Snowfall (daily) • Tamb (monthly avg.) • POA (monthly sum) • RH (monthly avg.) • Array geometry
Output	• Snow coverage • Snow loss factor (hourly)	• Snow loss factor (monthly)
Validation	Based on 2 years of data for 6 PV sites in Colorado and Wisconsin. Fixed tilt only.	Based on a fixed-tilt array with different inclinations. Not validated for tracker systems but provides suggestions.

Snow Loss Factor Boxplot in PVRADAR Web-App



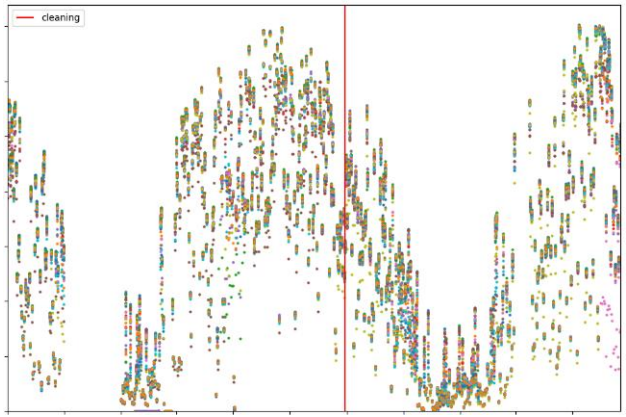
From Snow Loss Factor to Snow Energy Losses



Organic / Pollen Soiling

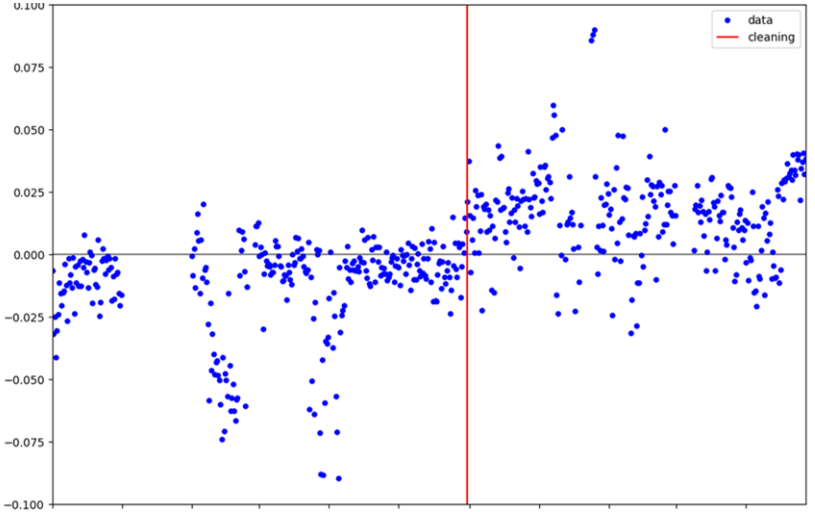
Location in Germany: 50% of inverters cleaned after 4 years

Raw data: total daily yield per inverter



filters out:
low irradiance
partial shading
inverter issues
…

Relative production increase comparing cleaned and uncleaned inverters.



$$\Delta = \frac{avg(P_{with\ \ cleaning}) - avg(P_{no\ cleaning})}{avg(P_{with\ cleaning})}$$

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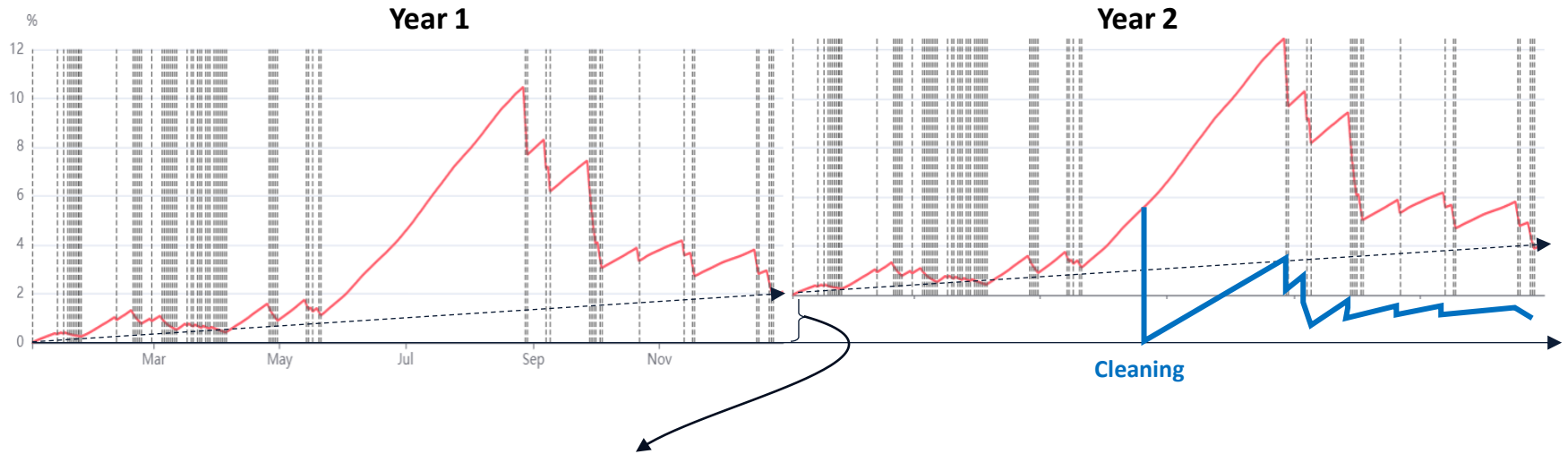
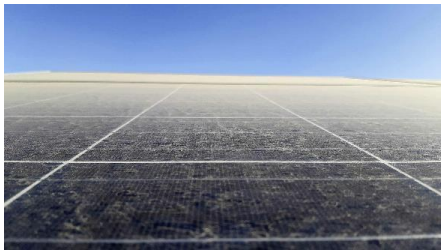
The problem of Hard or Sticky Soiling





Soiling from pollen and other organic material.

The cleaning optimization problem is not how many times per year, but every how many years!

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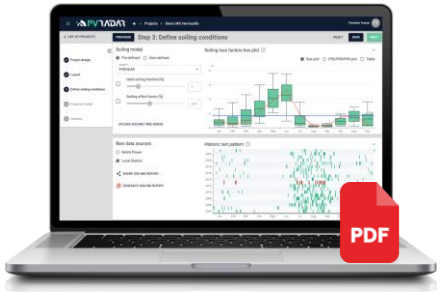
Modeling Platform

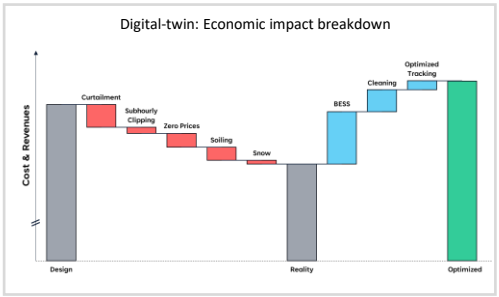


Ready to use tools for soiling & snow loss estimation and cleaning optimization

Python Package

Toolbox to develop and validate your own internal models

Custom Developments



Custom digital twins to quantify site specific losses and gains

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Thank You