Optimization and Economics of Large-Scale Photovoltaic Soiling Loss Mitigation

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Sole4PV (Soiling Live Estimation for Photovoltaics)

Project funded by the **Italian Ministry of University and Research** under the 2019 **«Rita Levi Montalcini» Program** for Young Researchers

SOiling Live Estimation for PhotoVoltaics

Agenda

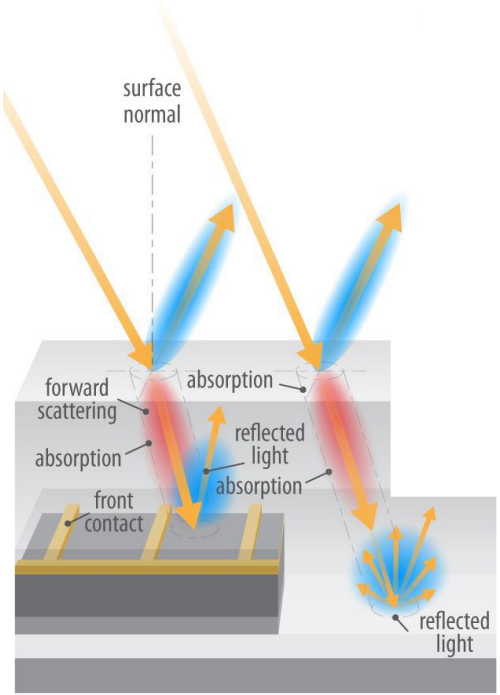
- Introduction: soiling definition and impact
- Research Question
- Methodology
- Results and Discussions
- Conclusions and Future Work

NoSoilPV: Novel Soiling Identification Logics for Photovoltaics
Awarded 2017 MSCA IF proposal (Agreement No. 793120)

Photovoltaic Soiling: definition

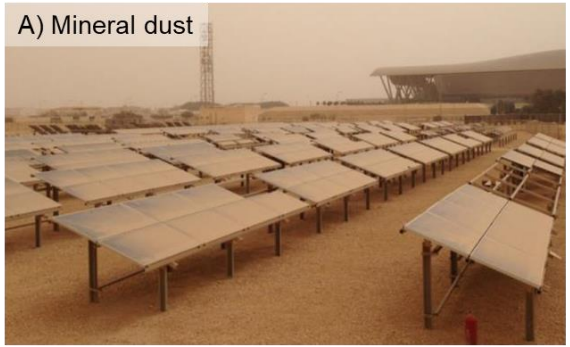
Deposition of dust, particles, dirt on the surface of PV modules.

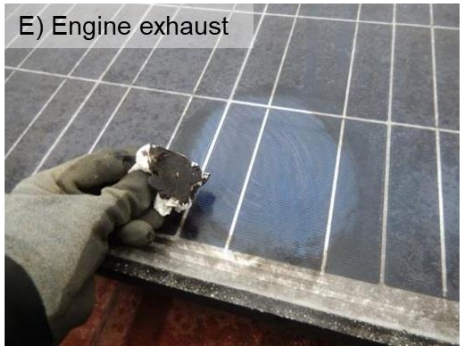
Soiling absorbs, reflects, scatters part of the incoming sunlight.



Courtesy of Al Hicks, NREL, CO, USA

Photovoltaic Soiling





Ilse et al. “Techno-economical assessment of soiling losses in global solar energy production and mitigation strategies”, Joule (2019).

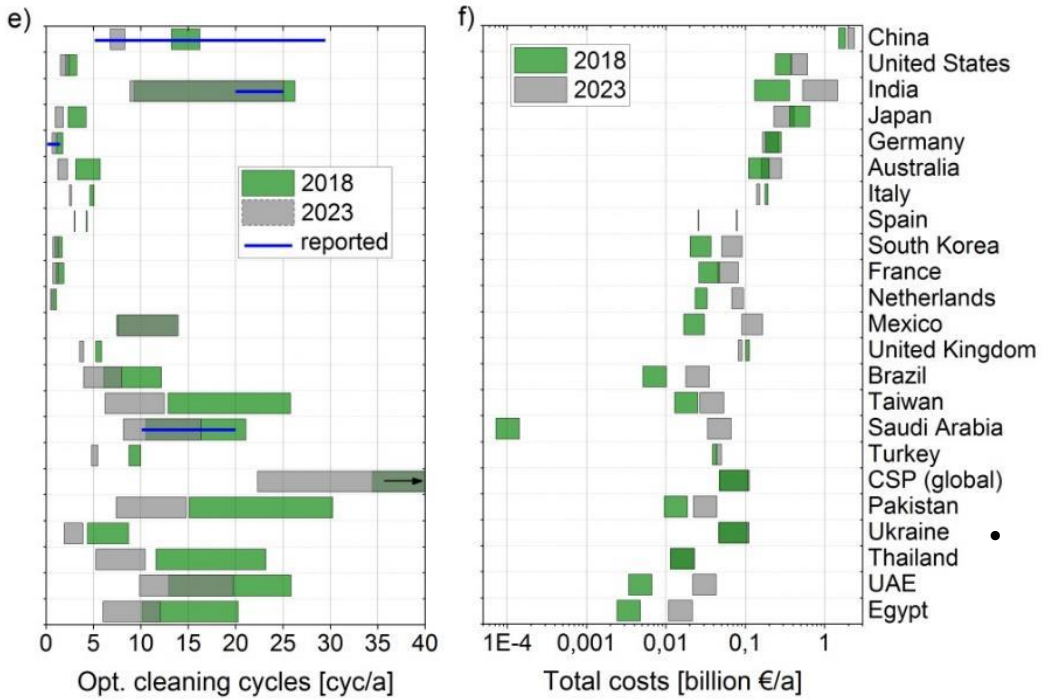
Photovoltaic Soiling


The energy yield of PV modules


The O&M costs


The uncertainty on the prediction of PV production.

Photovoltaic Soiling



In 2018:
3 to 4 % loss

➔ **3 to 5 billion € lost yearly**

Assuming a medium growth scenario for 2023:
4 to 7% loss in 2023.

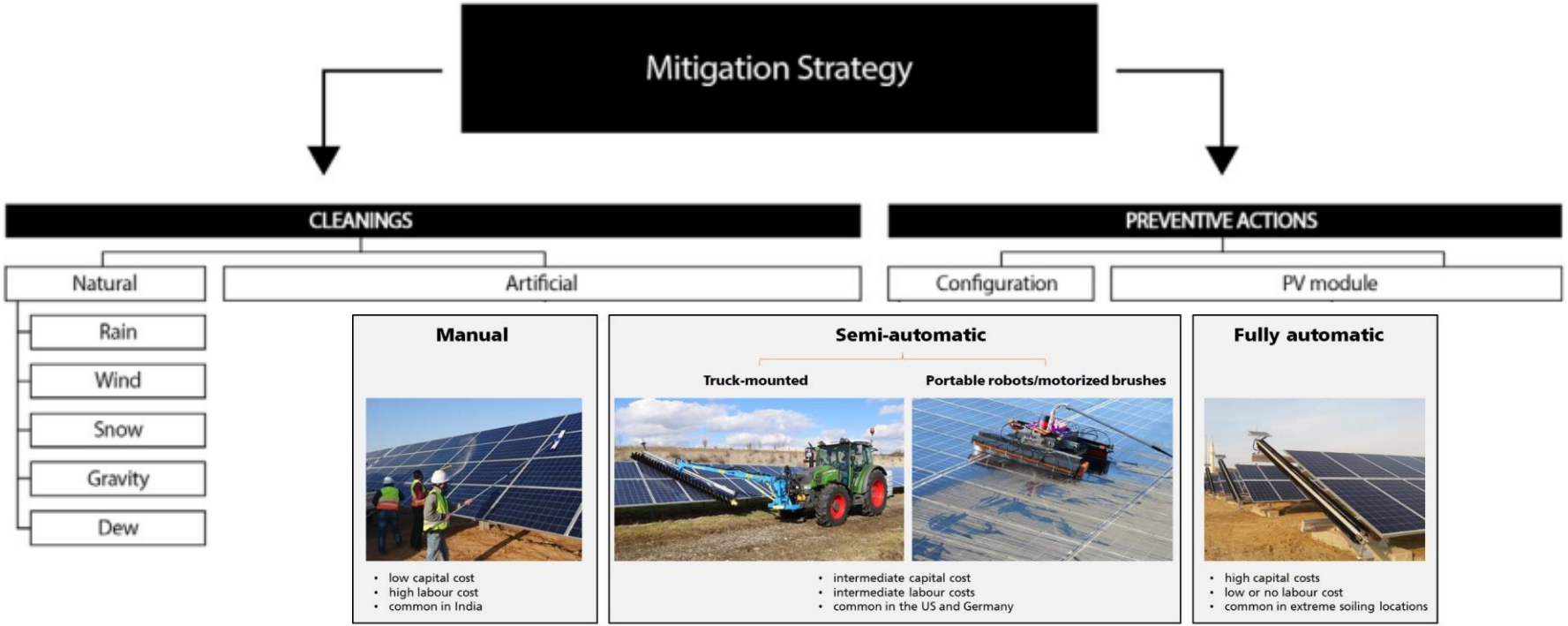
➔ **4 to 7 billion € lost** in 2023.

Loss raise driven by:
- Increased deployment in high-insolation and high-soiling regions
- Increased efficiency of the modules.

Ilse et al. “Techno-economical assessment of soiling losses in global solar energy production and mitigation strategies”, Joule (2019).

Photovoltaic Soiling

Differently from other losses, **soiling is reversible**.



Ilse et al. “Techno-economical assessment of soiling losses in global solar energy production and mitigation strategies”, Joule (2019).
G. Bessa, et al., Monitoring photovoltaic soiling : assessment , challenges , and perspectives, iScience (2021). doi:10.1016/j.isci.2021.102165.

Photovoltaic Soiling: Research Question

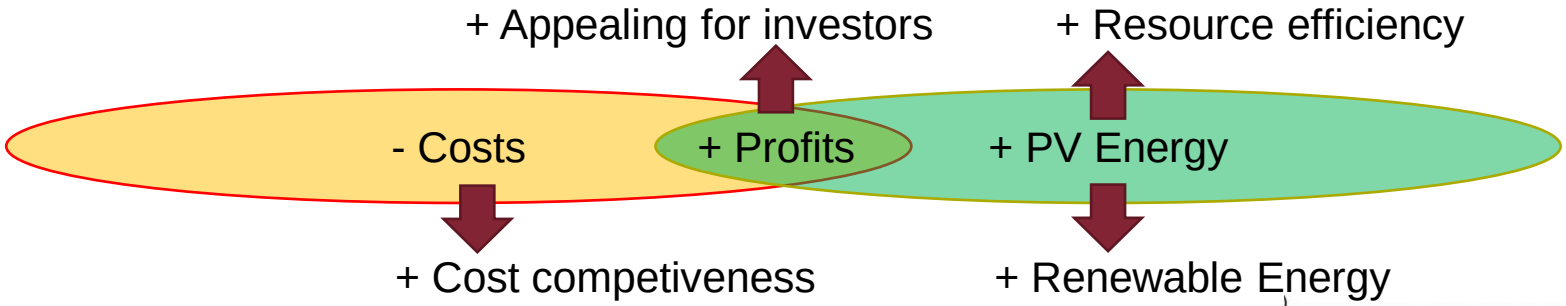
1. **Cleanings have a cost ➔ + cleanings, + energy, + costs**
2. **Natural events (e.g. rainfalls) can clean soiling.**

Cleaning optimization ➔ max(cleaning profits - cleaning costs)

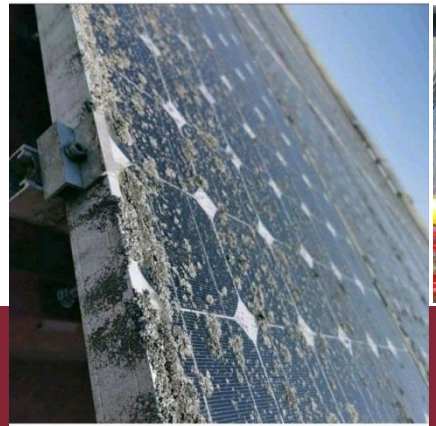
- Which is the optimal cleaning schedule?
- How does it change over time?

Photovoltaic Soiling: Audience Questions

1. Is cleaning optimization just about making profits?

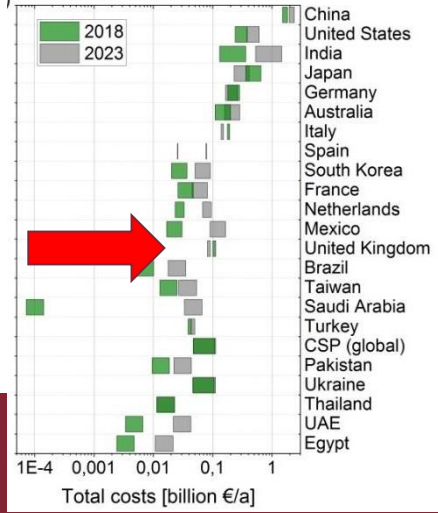


2. Is not of interest for rainy locations



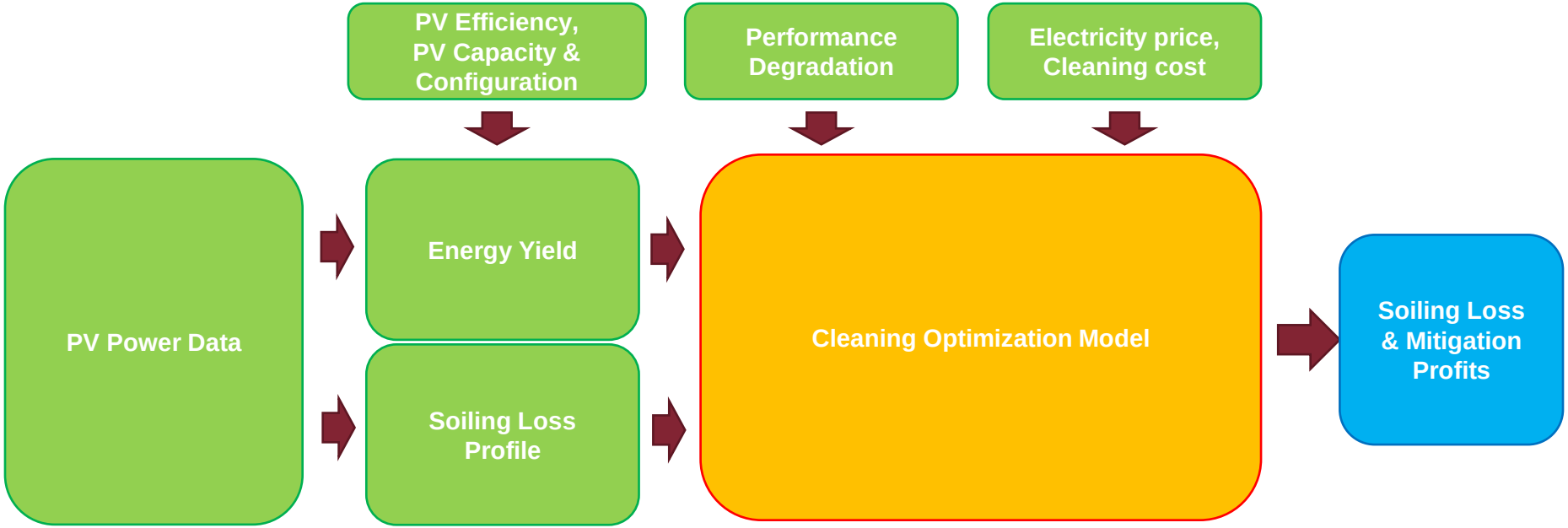

Devon & Cornwall, 2021.
plymouthherald.co.uk


Edinburgh, 2019
edinburghlive.co.uk

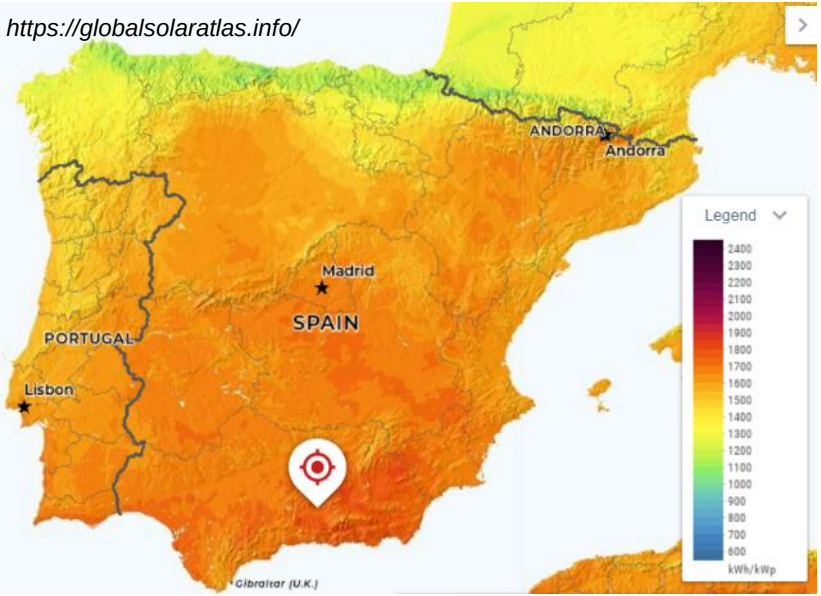


Belgium. *Courtesy of Kim Verduyckt, Solarco Cleaning*

Methodology



Methodology: Site



1 MW PV site in Granada, Spain

- Mono-crystalline Si
- 30° tilt angle, South orientation
- > 1700 kWh/kW AC energy yield
- AC and DC data for 2019

Methodology: Economics Metrics

The Levelized Cost of Electricity (**LCOE**) quantifies the cost of producing a kWh of electricity. The lower, the better.

$$LCOE = \frac{Installation\ Costs + \sum Yearly\ O\&M\ Costs\ /Discount}{\sum Yearly\ Energy\ Yield\ /Discount}$$

The Net Present Value (**NPV**) is commonly used in the private sector to evaluate the profitability of an investment. The larger, the better.

$$NPV = -Installation\ Costs + \sum \frac{Yearly\ Revenues - Yearly\ O\&M\ Costs}{Discount}$$

Same cleaning frequency throughout the lifetime of the PV system.

Installation Costs (700 €/kW)

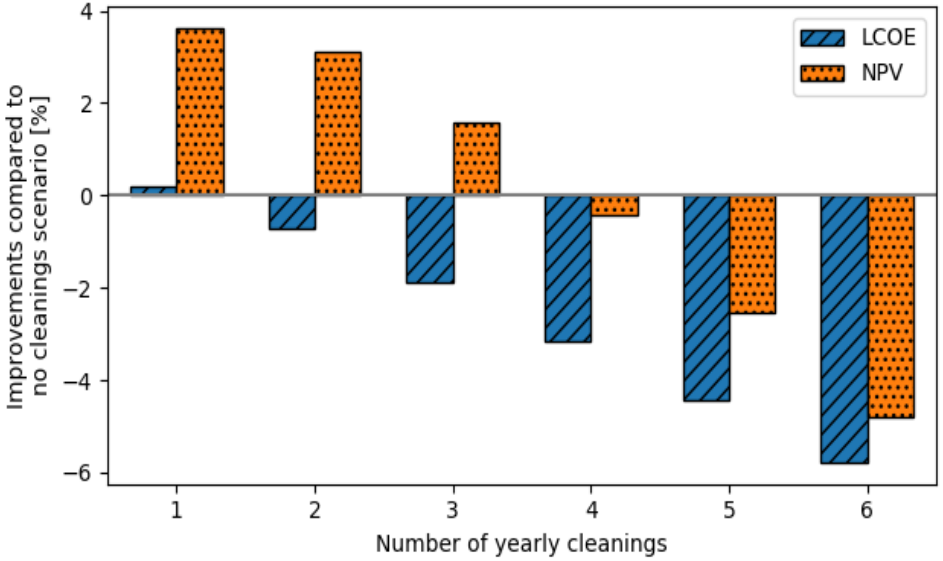
Yearly O&M Costs:
- Cleaning frequency
- Cleaning cost (**0.62 €/kW/cleaning**)
- ~~Cleaning cost variability~~

Yearly Energy Yield:
- AC Energy output
- Soiling Loss
- Degradation (-1 %/year)

Yearly Revenues:
- Yearly Energy Yield
- Electricity Price (**0.06 €/kWh**)
- ~~Electricity Price variability~~

L. Micheli, et al., Economics of seasonal photovoltaic soiling and cleaning optimization scenarios, Energy. 215 (2021) 119018. doi:10.1016/j.energy.2020.119018.

Results: Cleaning Frequency Optimization



- Both LCOE and NPV recommend 1 cleaning per year.
- Any number of cleanings up to 3 would be more profitable than no-cleaning.
- For LCOE, better no mitigation than cleaning more than once per year.

Positive improvement:
raise in NPV, drop in LCOE

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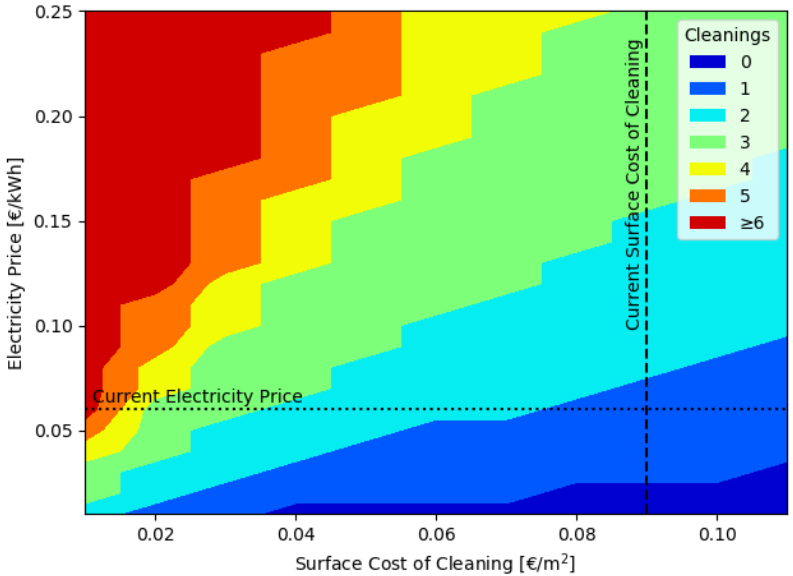

The optimal number of cleanings changes with the cleaning costs and the electricity price.

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$$NPV = -Installation\ Costs + \sum \frac{Yearly\ Revenues - Yearly\ O\&M\ Costs}{Discount}$$

~~Same cleaning frequency throughout the lifetime of the PV system.~~

Cleaning frequency optimized every year

Installation Costs (700 €/kW)

Yearly O&M Costs:
- Cleaning frequency
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Yearly Energy Yield:
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Yearly Revenues:
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L. Micheli, et al., Photovoltaic cleaning frequency optimization under different degradation rate patterns, 166 (2020). doi:10.1016/j.renene.2020.11.044.

Results: Cleaning Frequency Optimization

The number of cleanings can be optimized every year.

Revenues increasing if:

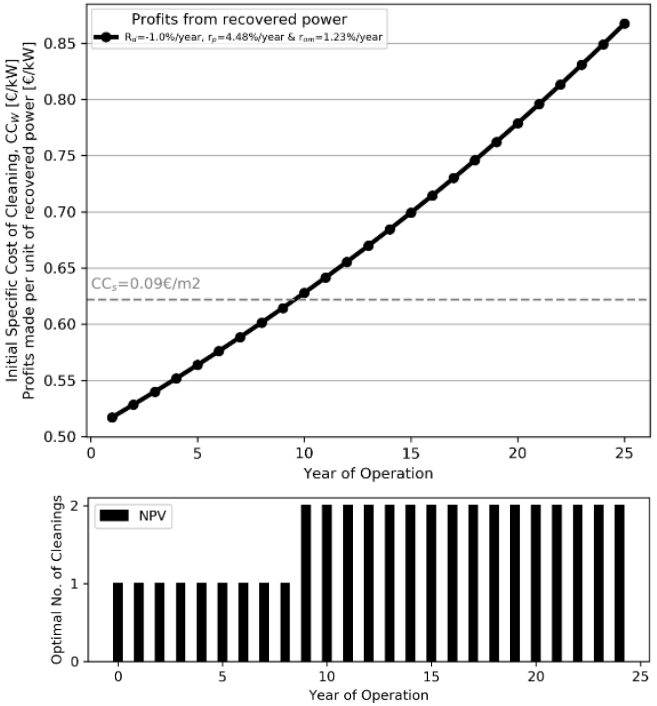
$$|R_D| < 1 - \frac{1 + r_{om}}{1 + r_p}$$

$$0.01 < 1 - \frac{1+0.01}{1+0.05}$$

$$0.01 < 1 - 0.96$$

True

R_D: degradation rate
r_{om}: cleaning cost variability
r_p: electricity price variability



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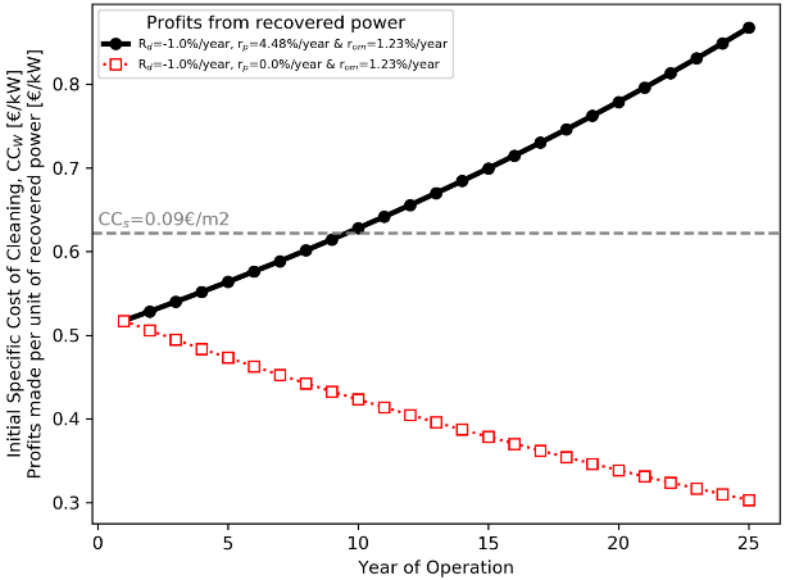
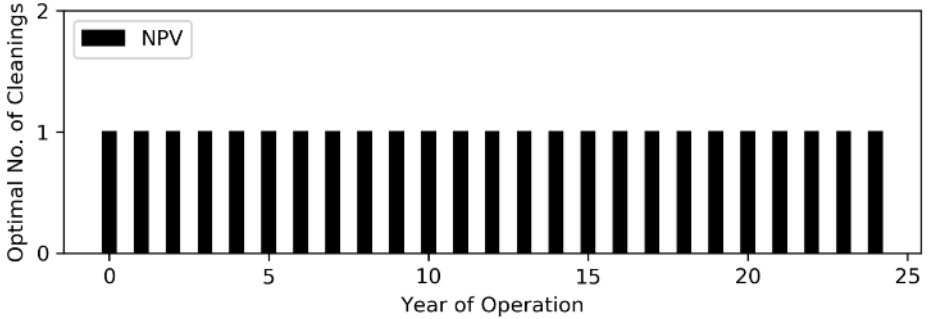


Fixed Electricity Price (r_p = **0.0%**/year):

$$0.01 < 1 - \frac{1+0.01}{1+\mathbf{0.00}}$$

$$0.01 < 1 - 1.01$$

False



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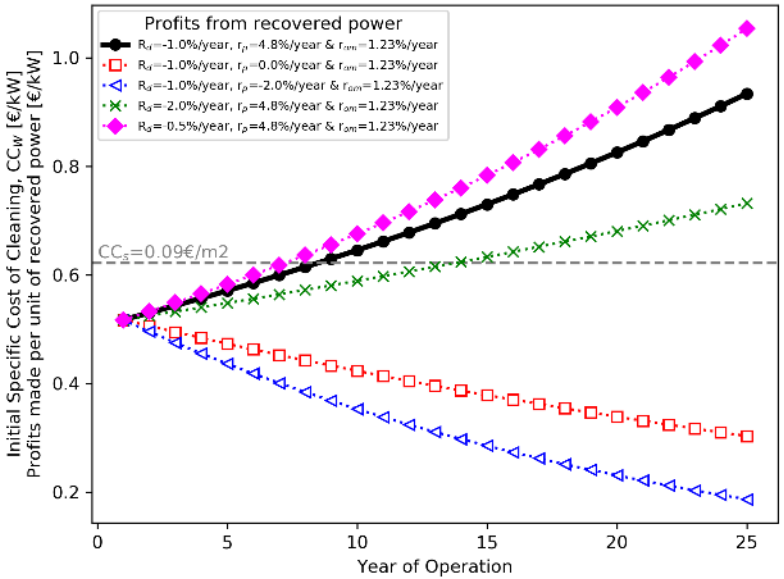
Results: Cleaning Frequency Optimization



Higher Degradation Rate (R_D = **-2.0%**/year):

$$\mathbf{0.02} < 1 - \frac{1+0.01}{1+0.05}$$

$$0.02 < 1 - 0.96$$

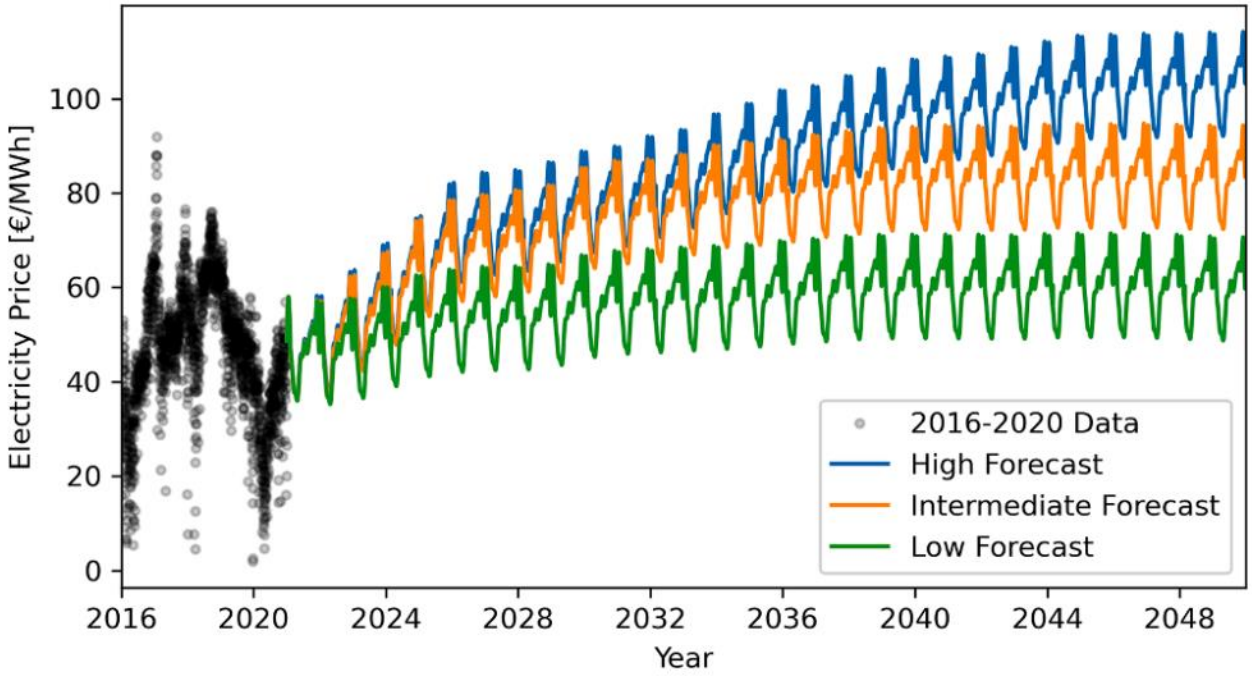
Lower Degradation Rate (r_p = **-0.5%**/year):

$$\mathbf{0.005} < 1 - \frac{1+0.01}{1+0.05}$$

$$0.005 < 1 - 0.96$$

L. Micheli, et al., Photovoltaic cleaning frequency optimization under different degradation rate patterns, 166 (2020). doi:10.1016/j.renene.2020.11.044.

Results: Cleaning Frequency Optimization



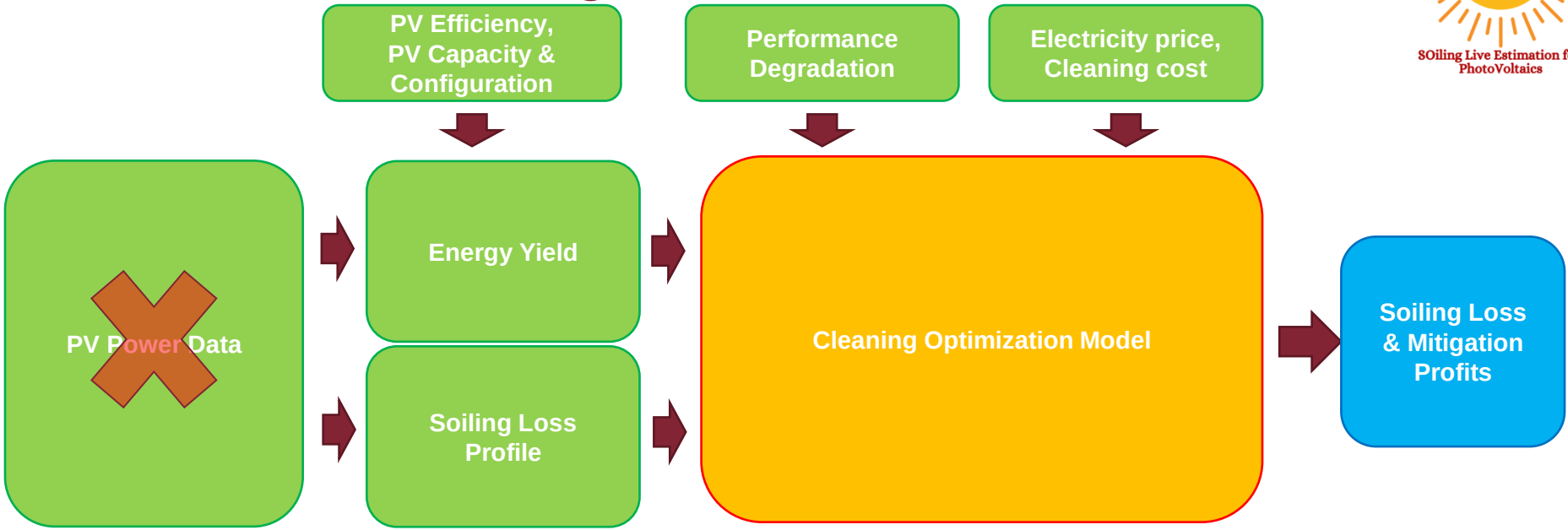
Higher electricity prices will incentivize O&M and soiling mitigation in future.

L. Micheli, Energy and economic assessment of floating photovoltaics in Spanish reservoirs : cost competitiveness and the role of temperature, Sol. Energy. (2021). doi:10.1016/j.solener.2021.08.058.

Conclusions: Cleaning Frequency Optimization

- Soiling has a significant impact on PV systems worldwide, but it can be mitigated.
- Cleaning optimization allows maximizing the revenues, minimizing the costs and increasing the PV share.
- The role of electricity price, cleaning cost and system degradation has to be accounted.

Sole4PV: Soiling Live Estimation for PV



Sole4PV

PV Efficiency, PV Capacity & Configuration

Performance Degradation

Electricity price, Cleaning cost

Irradiance, Temperature

Energy Yield

Environmental Parameters

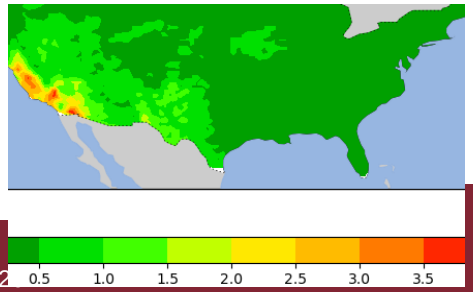
Soiling Loss Profile

Soiling Mitigation Model

Soiling Loss & Mitigation Profits

Inverter Saturation

Anti-Soiling Coatings



L. Micheli, et al., Tracking Soiling Losses: Assessment, Uncertainty, and Challenges in Mapping, IEEE J. Photovoltaics. 12 (2022) 114–118. doi:10.1109/JPHOTOV.2021.3113858.

Grazie mille!

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