Optimization and Economics of Seasonal Soiling Mitigation for Utility Scale PV Systems

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CEAEMA

NoSoilPV

Novel Soiling Identification Logics for Photovoltaics

Awarded 2017 MSCA IF proposal *(Agreement No. 793120)*

UJA.es

EFQM Recognised for Excellence 5 Star - 2017

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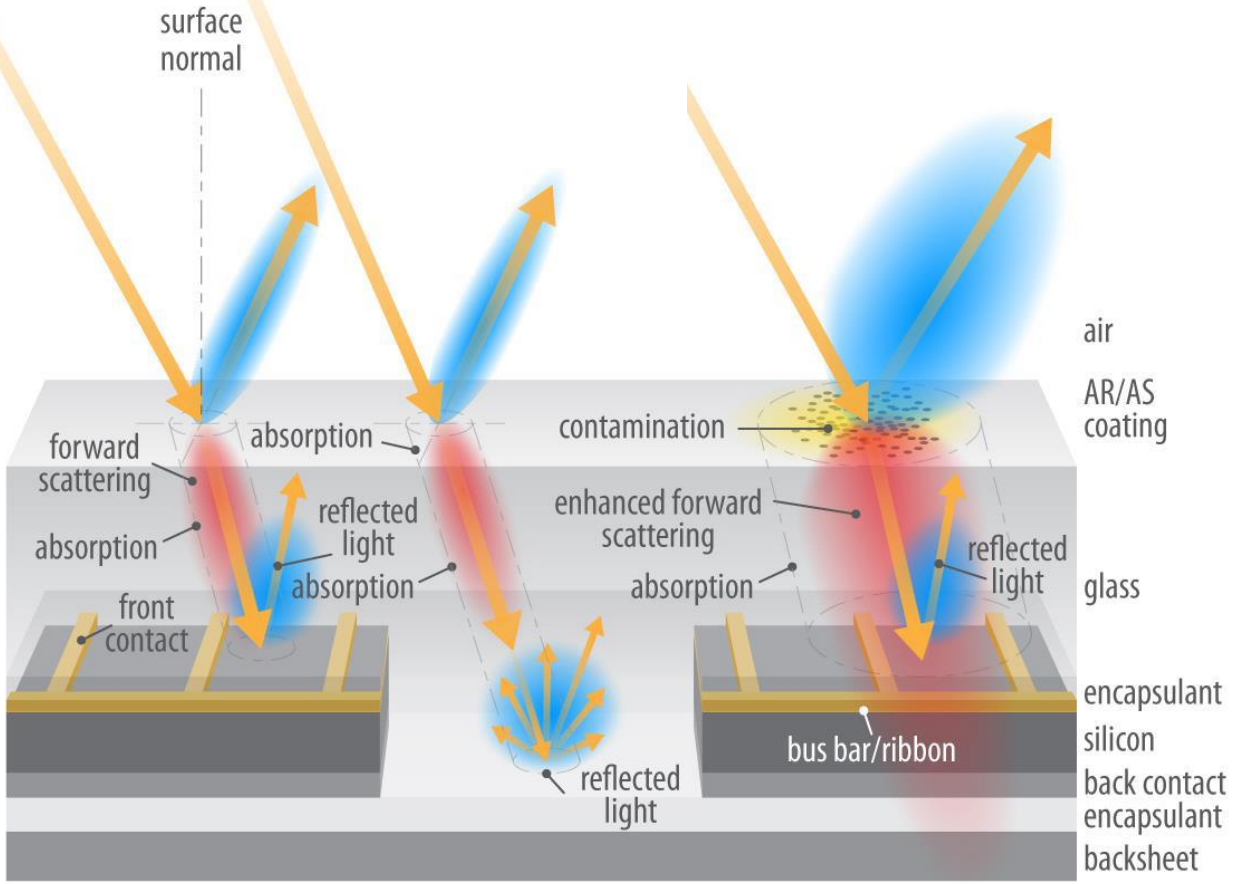
PearlPV

Online Workshop WG5

2021-01-12

Introduction: Definition of Soiling

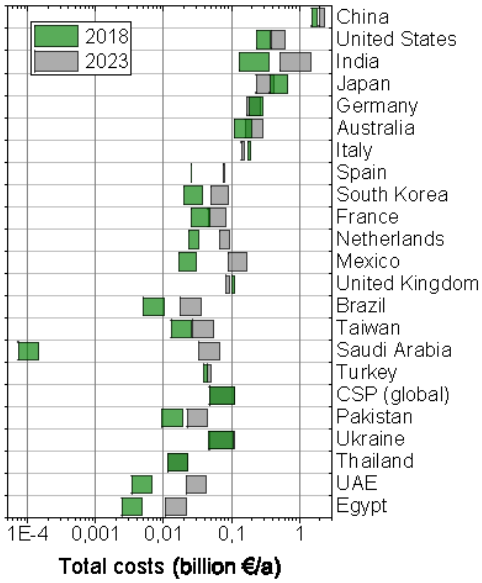
Deposition of dust, particles, dirt on the surface of PV modules



Soiling absorbs, reflects, scatters part of the incoming sunlight

*G.P. Smestad, T.A. Germer, H. Alrashidi, E.F. Fernández, S. Dey, H. Brahma, N. Sarmah, A. Ghosh, N. Sellami, I.A.I. Hassan, M. Desouky, A. Kasry, B. Pesala, S. Sundaram, F. Almonacid, K.S. Reddy, T.K. Mallick, and L. Micheli, Sci. Rep. **10**, 58 (2020).*

Introduction: Soiling Impact



Currently, soiling reduces the current global solar power production by at least 3-4%, with at least **3-5 billion € annual revenue losses**.

Cleanings are the most common soiling mitigation solution.

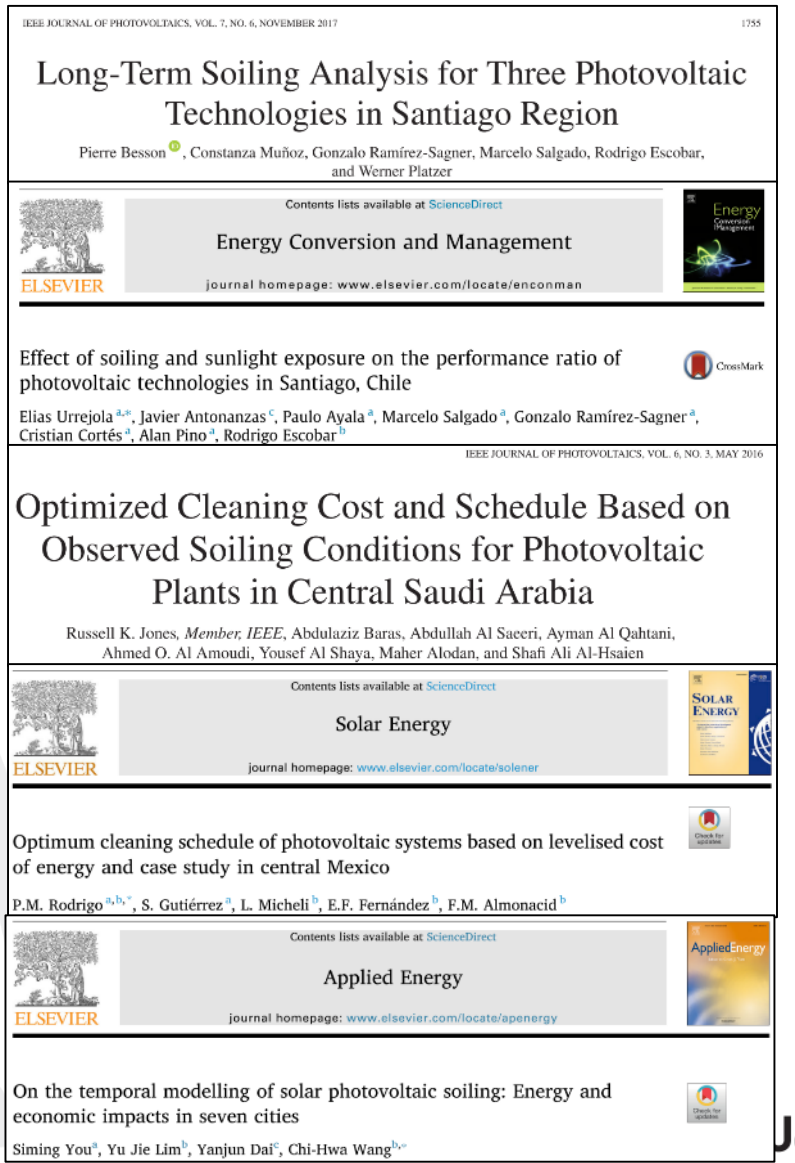
Frequency and **Timing** have to be optimized:

to maximize the difference between revenues and cleaning costs (in Spain ˜0.09€/m^2).

Introduction: Cleaning Optimization

Several factors affect optimization:

- **Cost of cleaning**
- **Soiling accumulation rate**
- **Capacity factor**
- **Electricity Price**
- **PV module efficiency**



IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 7, NO. 6, NOVEMBER 2017 1755

Long-Term Soiling Analysis for Three Photovoltaic Technologies in Santiago Region

Pierre Besson, Constanza Muñoz, Gonzalo Ramírez-Sagner, Marcelo Salgado, Rodrigo Escobar, and Werner Platzer

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

ELSEVIER

Effect of soiling and sunlight exposure on the performance ratio of photovoltaic technologies in Santiago, Chile

Elias Urrejola [a,*], Javier Antonanzas [c], Paulo Ayala [a], Marcelo Salgado [a], Gonzalo Ramírez-Sagner [a], Cristian Cortés [a], Alan Pino [a], Rodrigo Escobar [b]

IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 6, NO. 3, MAY 2016

Optimized Cleaning Cost and Schedule Based on Observed Soiling Conditions for Photovoltaic Plants in Central Saudi Arabia

Russell K. Jones, *Member, IEEE*, Abdulaziz Baras, Abdullah Al Saeeri, Ayman Al Qahtani, Ahmed O. Al Amoudi, Yousef Al Shaya, Maher Alodan, and Shafi Ali Al-Hsaien

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Solar Energy

journal homepage: www.elsevier.com/locate/solener

ELSEVIER

Optimum cleaning schedule of photovoltaic systems based on levelised cost of energy and case study in central Mexico

P.M. Rodrigo [a,b,*], S. Gutiérrez [a], L. Micheli [b], E.F. Fernández [b], F.M. Almonacid [b]

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

ELSEVIER

On the temporal modelling of solar photovoltaic soiling: Energy and economic impacts in seven cities

Siming You [a], Yu Jie Lim [b], Yanjun Dai [c], Chi-Hwa Wang [b,*]

National Renewable Energy Laboratory (NREL), NREL/TP-7A40-73822 (2018).

Introduction: Aim

- Assess the effectiveness of soiling mitigation in Southern Spain (**low** losses, **significant** seasonality).
- Compare the cleaning recommendations of the different economic metrics.
- Analyze the effect of electricity price and cleaning costs.
- Evaluate the impact of performance degradation.

*L. Micheli, E.F. Fernández, J.T. Aguilera, and F. Almonacid, Energy **215**, 119018 (2021).*
*L. Micheli, M. Theristis, D.L. Talavera, F. Almonacid, J.S. Stein, and E.F. Fernández, Renew. Energy **166**, 136 (2020).*

Agenda

Methodology:

- Soiling and Economic Metrics
- PV Site: Performance & Soiling Extraction

Results

- Cleaning Optimization
- Effect of Electricity Price and Cleaning Costs
- Effect of Performance Degradation

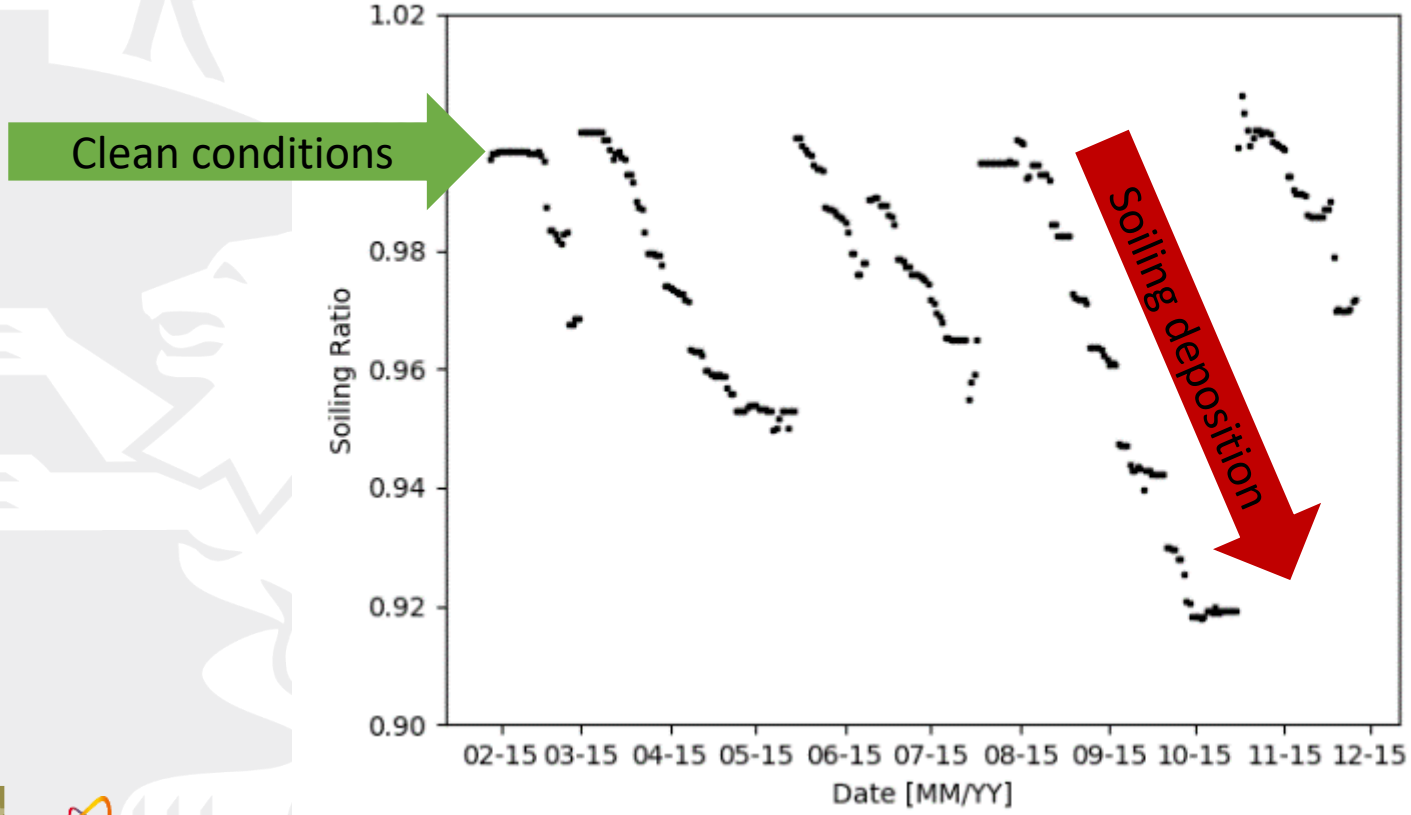
Conclusions

Methodology: Soiling Indexes

Soiling is commonly quantified through the **Soiling Ratio:**

1 in conditions of no soiling (0% losses)

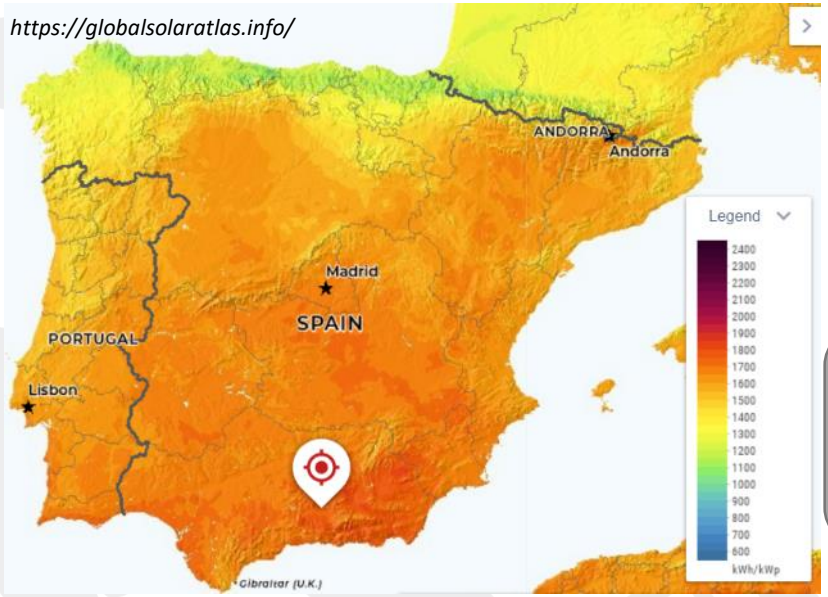
< 1 while soiling deposits



International Electrotechnical Commission, "Photovoltaic system performance – Part 1: Monitoring (IEC 61724-1, Edition 1.0, 2017-03)" (2017).

Soiling Rate: daily derate in Soiling Ratio [%/day]. Conventionally ≤ 0%/day.

Methodology: PV 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

Modelled Performance Degradation

Electricity price, Cleaning cost

PV Performance Data

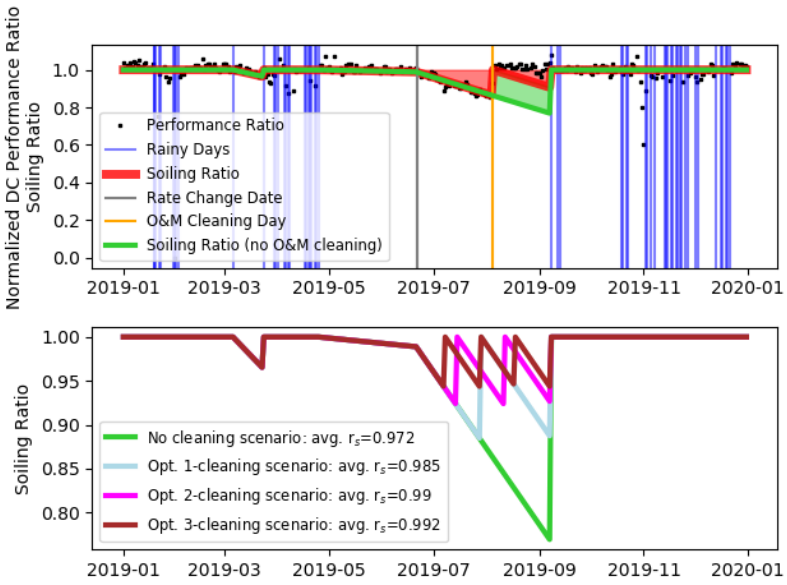
Energy Yield

Soiling Loss Profile

Cleaning Optimization Model

LCOE NPV

Methodology: Soiling Loss



- Performance ratio extracted from DC power of one string.
- Soiling profile extracted from performance ratio.
- Soiling rate change on June 22:
  - Before: -0.02 %/day
  - After: -0.28 %/day
- Cleaning performed by the O&M team on August 5.
- Maximum soiling extent was modelled:
  - Average loss: 2.8 %
  - Maximum loss: 23.1 % (end of summer)
- Various cleaning frequencies modelled: from 0 to 6 cleanings per year.

Assumption: same soiling profile every year*

* Subject of: *L. Micheli, E.F. Fernández, and F. Almonacid, Under Review.*

Methodology: Economic 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)

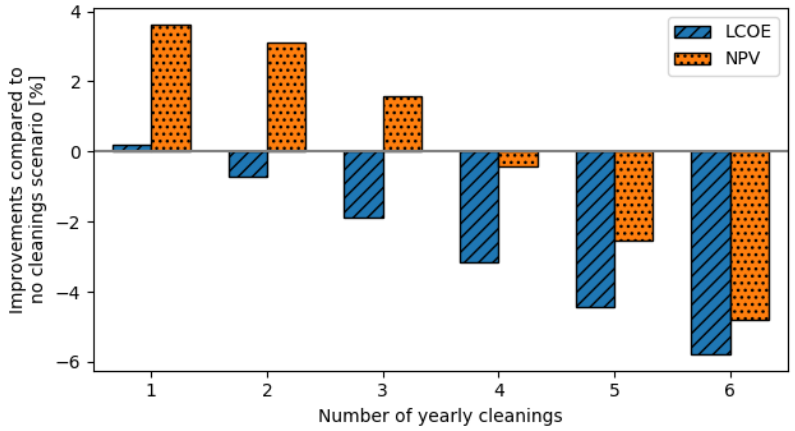
Yearly O&M Costs:
- Cleaning frequency
- Cleaning cost (**0.62 €/kW/cleaning**)
- Cleaning cost variability

Yearly Energy Yield:
- DC Power output
- Soiling Loss
- Degradation (**-1 %/year**)

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

+ Cleanings → + Yearly Energy Yield, + Yearly Revenues, + Yearly O&M Costs

Results: Cleaning No. Optimization

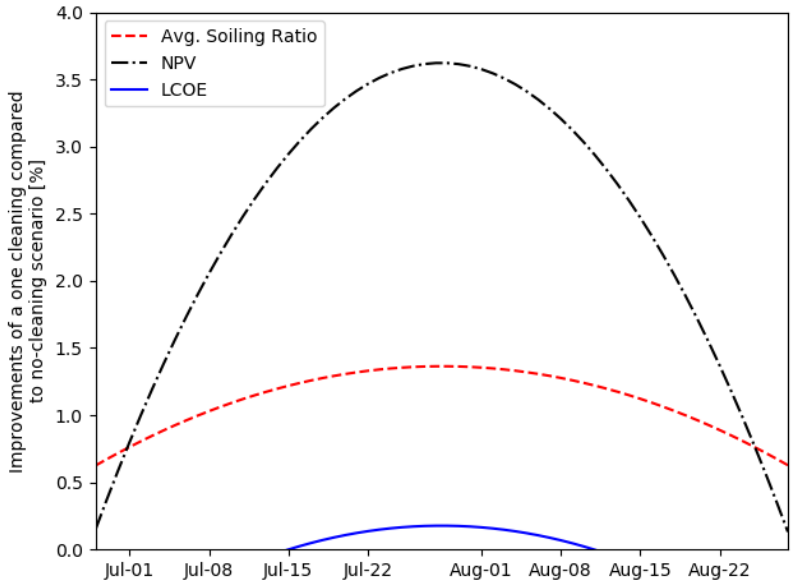


- Both LCOE and NPV recommend 1 cleaning per year.
- Any number of cleanings up to 3 would be more profitable than no-cleaning.
- For LCOE, better no mitigation than cleaning more than once per year.

Positive improvement:

raise in NPV, drop in LCOE

Results: Cleaning Date Optimization



Most effective cleanings:

July 22 to August 1

Positive LCOE window:

± 13 days

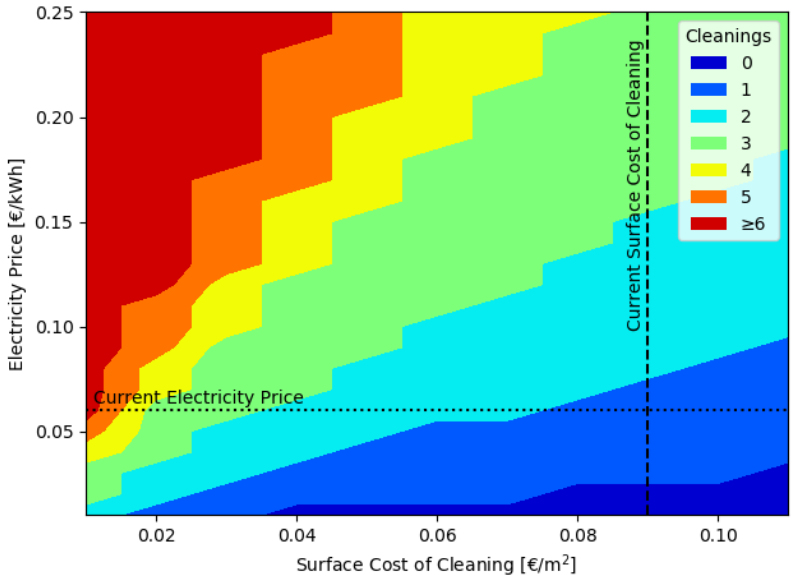
Positive NPV window:

± 31 days.

Positive improvement:

raise in soiling ratio (drop in soiling losses), raise in NPV, drop in LCOE

Results: Sensitivity Analisys



- The optimal number of cleanings changes with the cleaning costs and the electricity price.
- Higher module's efficiency raises the profits of soiling mitigation (*+0.1% in profits per unit of efficiency).*

Methodology: Economic 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.~~
Cleaning frequency optimized every year

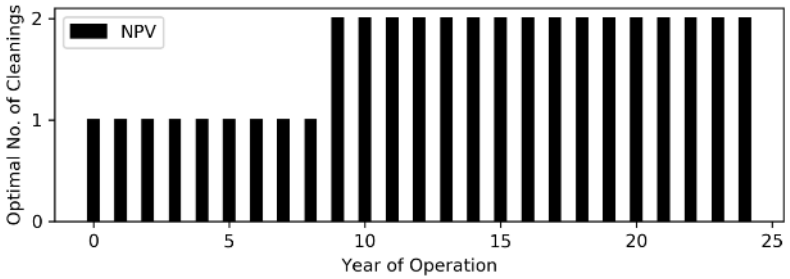
Installation Costs (700 €/kW)

Yearly O&M Costs:
- Cleaning frequency
- Cleaning cost (**0.62 €/kW/cleaning**)
- Cleaning cost variability (**+1.23%/year**)

Yearly Energy Yield:
- DC Power output
- Soiling Loss (**-1 %/year**)
- Degradation

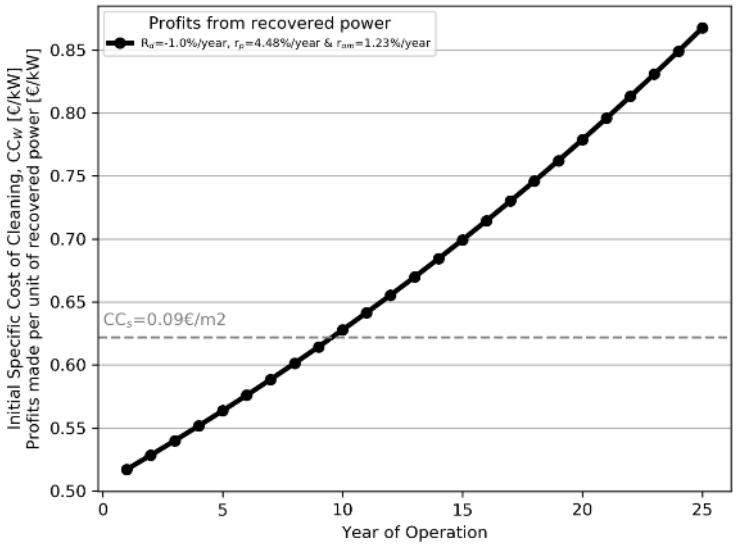
Yearly Revenues:
- Yearly Energy Yield
- Electricity Price (**0.06 €/kWh**)
- Electricity Price variability (**+4.48%/year**)

Results: Yearly Optimization



The number of cleanings can be optimized every year.

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



Profits increasing if:

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

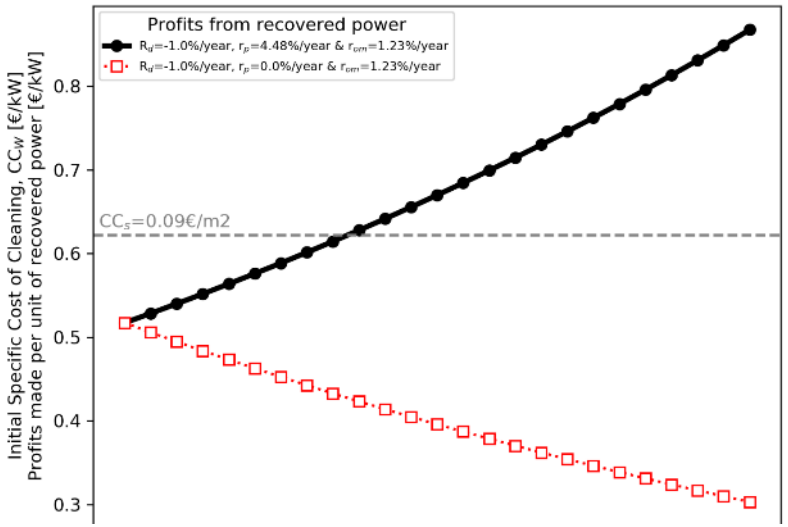
$$0.01 < 1 - \frac{1+0.01}{1+0.05}$$

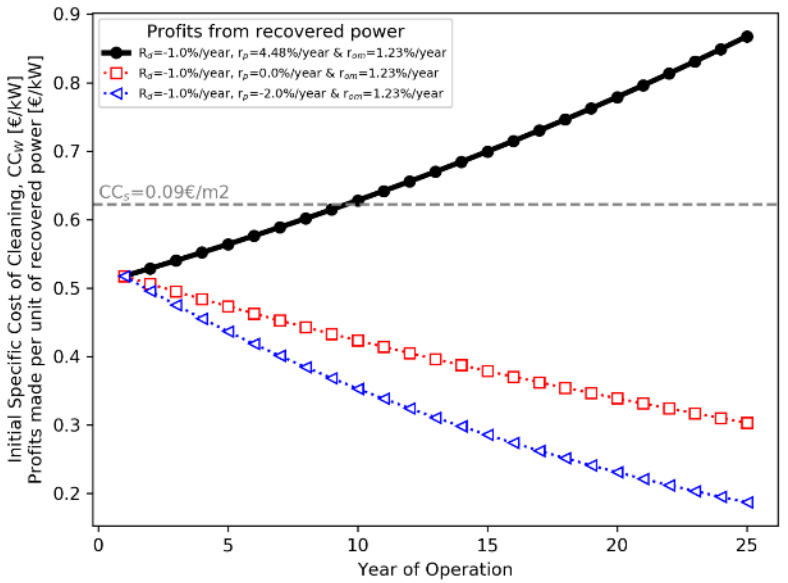
$$0.01 < 1 - 0.96$$

True

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

Results: Yearly Optimization



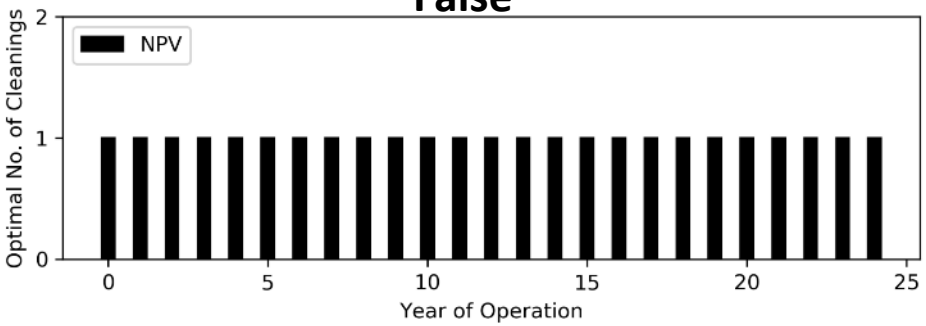


Fixed Electricity Price (r_p = **0.0%**/year):

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

$$0.01 < 1 - 1.01$$

False

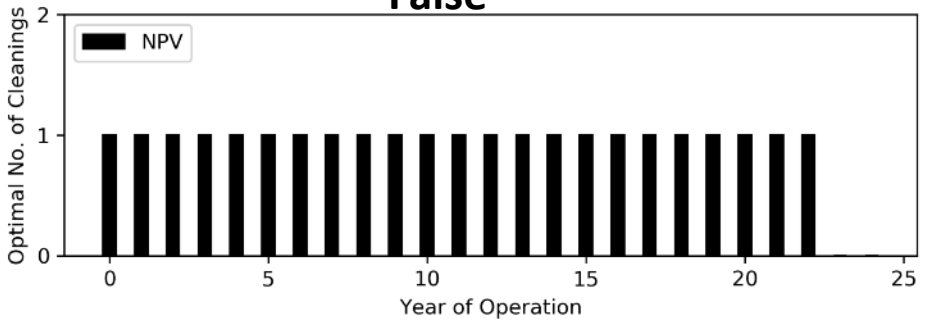


Lowering Electricity Price (r_p = **-2.0**%/year):

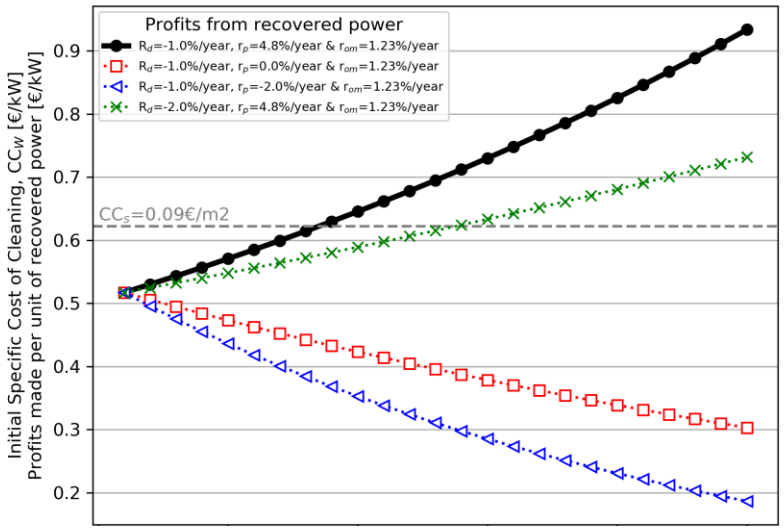
$$0.01 < 1 - \frac{1+0.01}{1-\mathbf{0.02}}$$

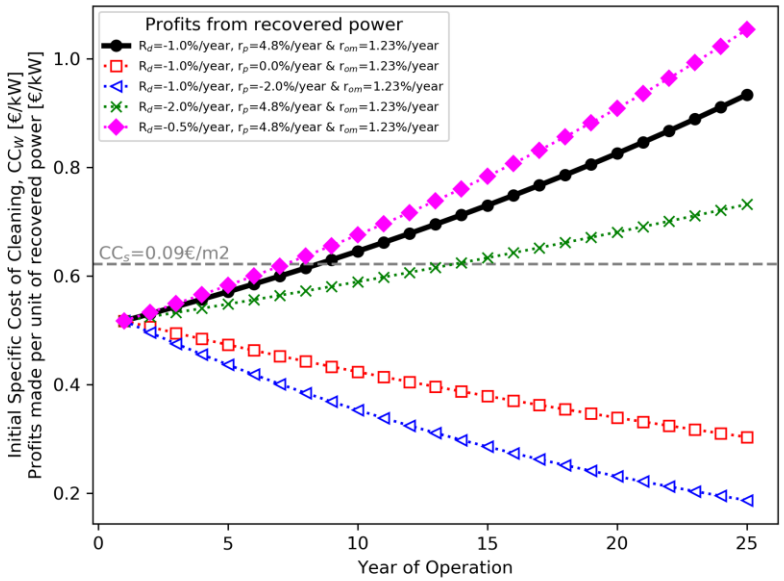
$$0.01 < 1 - 1.03$$

False



Results: Yearly Optimization



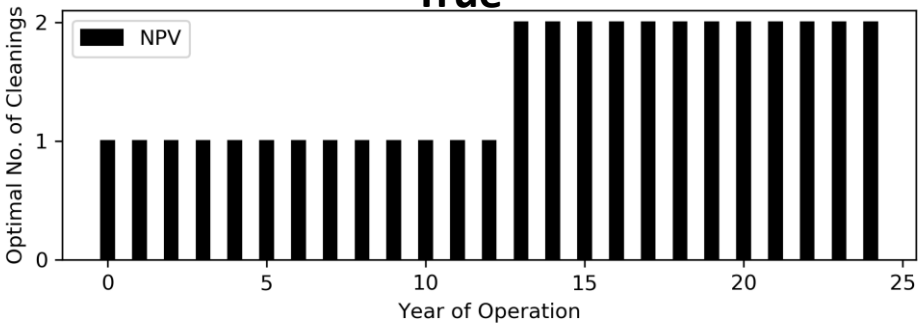


Higher Degradation Rate (R_D = **-2.0%**/year):

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

$$0.02 < 1 - 0.96$$

True

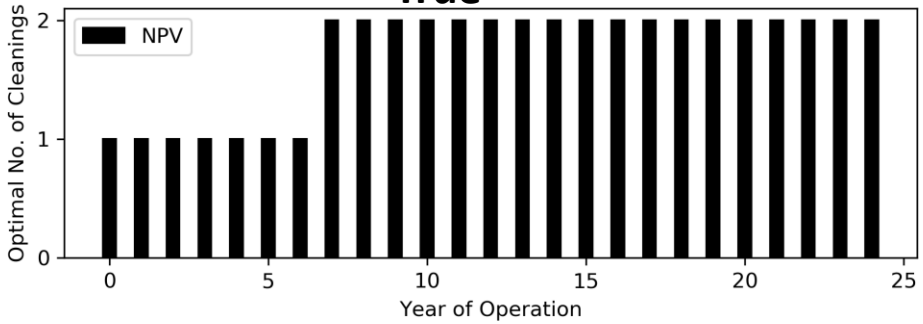


Lower Degradation Rate (r_p = **-0.5**%/year):

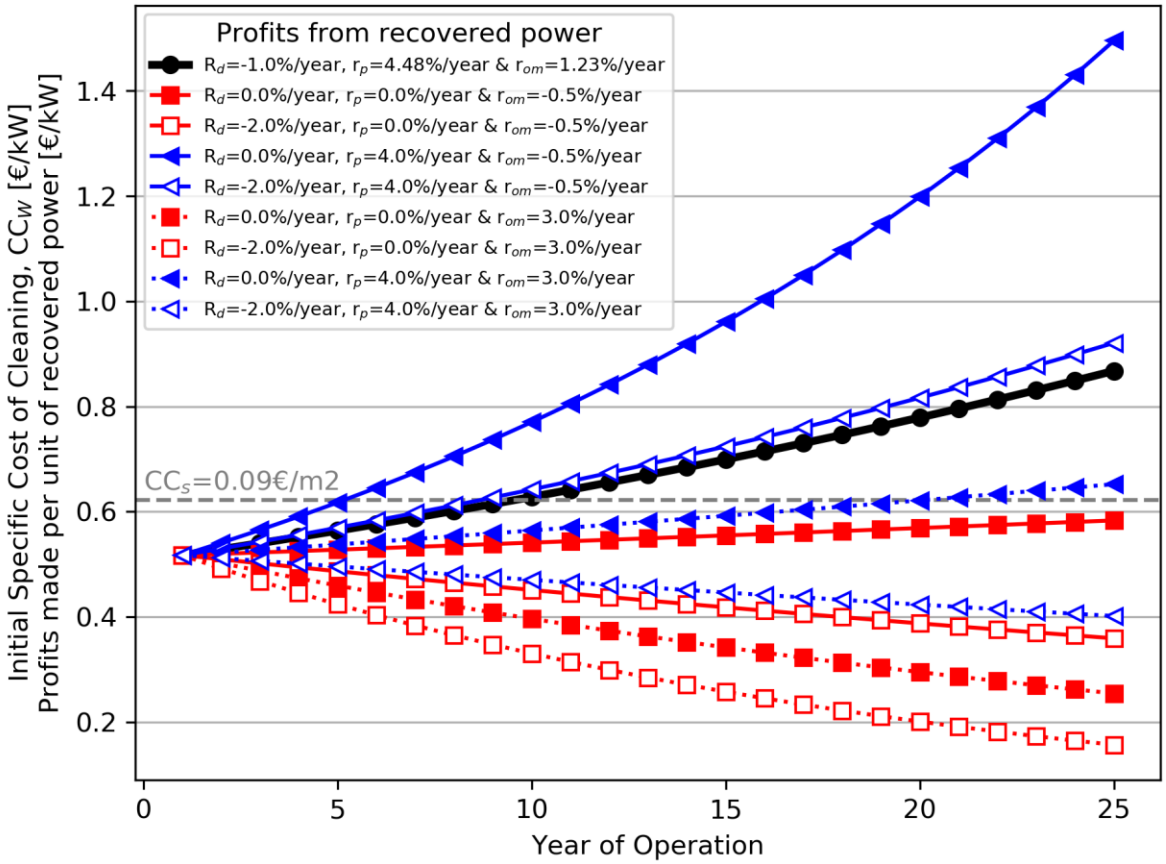
$$\mathbf{0.005} < 1 - \frac{1+0.01}{1+0.05}$$

$$0.005 < 1 - 0.96$$

True



Results: Yearly Optimization



Conclusions

- «Limited» average soiling losses (˜3%), but significantly seasonal (>20%).
- Increase in NPV as high as 4% with soiling mitigation.
- One or two yearly cleanings are recommended, in summer.
- LCOE and NPV recommend different cleaning strategies.
- Degradation, price and cleaning cost affect significantly the soiling mitigation strategy.

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Thanks for your attention!

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Thanks to my coauthors: E. F. Fernandez [1], M. Theristis [2], J. Aguilera [1], D. L. Talavera [1], J. S. Stein [2], F. Almonacid [1]

[1] *University of Jaén, Spain* [2] *Sandia National Laboratories, USA*

*The authors acknowledge **Sonnedix** for sharing commercial PV performance data. In particular, they wish to thank Juan M. Fernández and Ruth Prieto for the support in accessing and analyzing the data.*

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*The work of Florencia Almonacid and Eduardo F. Fernandez was funded through the project ROM-PV which is supported under the umbrella of **SOLAR-ERA.NET Cofund**.*

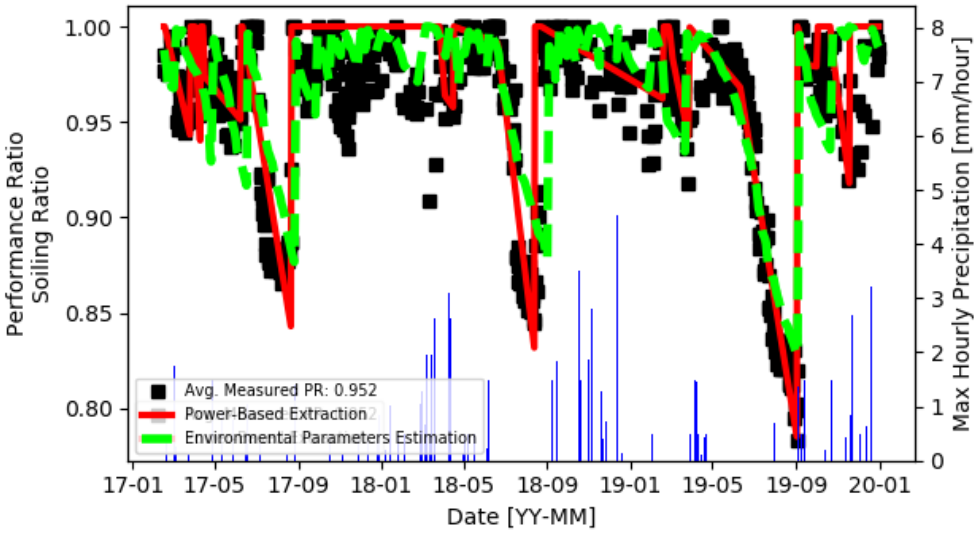
PP2: Economic parameters

Parameter	Symbol	Value	Units
Years of operation	N	25	years
O&M costs, cleaning excluded	OM_n	15	€/kW/year
Installation Costs	C	700	€/kW
Initial Surface Cleaning Cost	CC_s	0.09	€/m^2/cleaning
Specific Cost of Cleaning	CC_w	0.62	€/kW/cleaning
Discount Rate	d	6.4	%/year
Annual escalation rate of the operation and maintenance cost	r_{om}	1.23	%/year
Income Tax	T	25	%
Depreciation period	N_d	20	years
Average annual rate of increase in the electricity price	r_p	4.48	%/year
Value added tax	VAT	21	%
Initial pre-tax price of electricity	$p_{pre\text{-}tax}$	0.04778	€/kWh

Ongoing Work

This work is based on the assumption of soiling repeatability.

DC Power

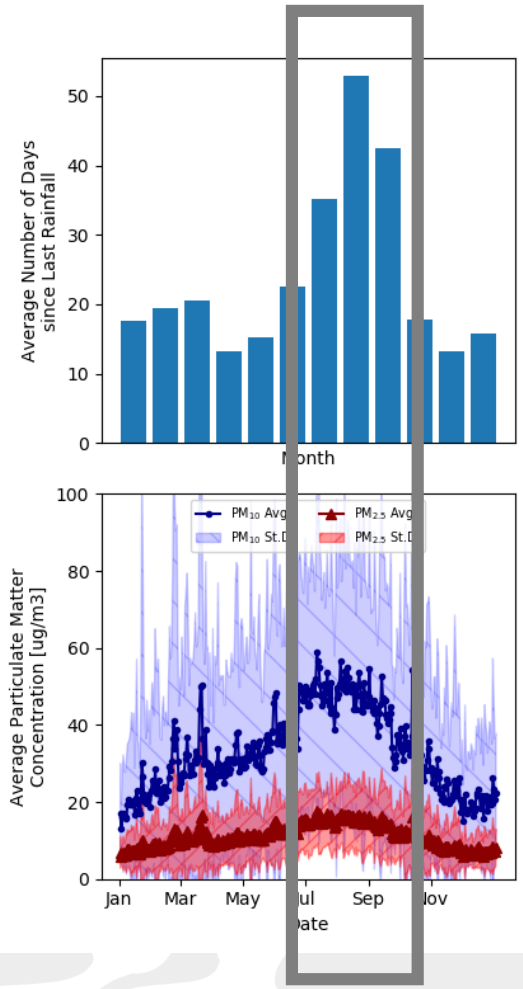


Particle Matter

Rainfall

L. Micheli, E.F. Fernández, and F. Almonacid, Under Review.

Ongoing Work



Soiling Characterization

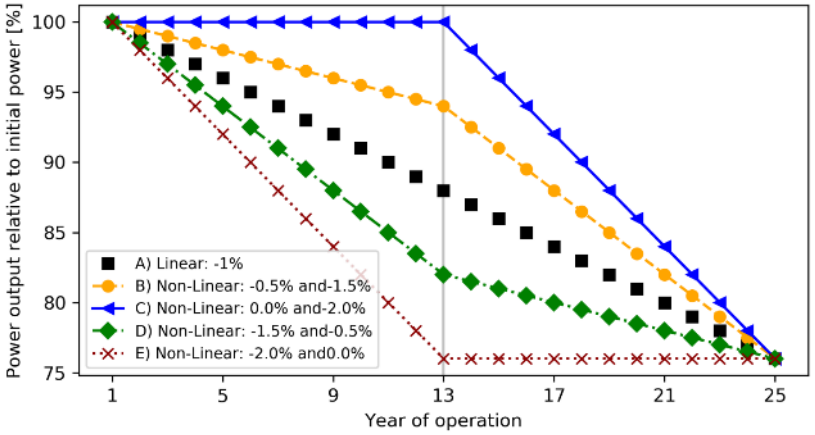
Cleaning Optimization

No need for power data!

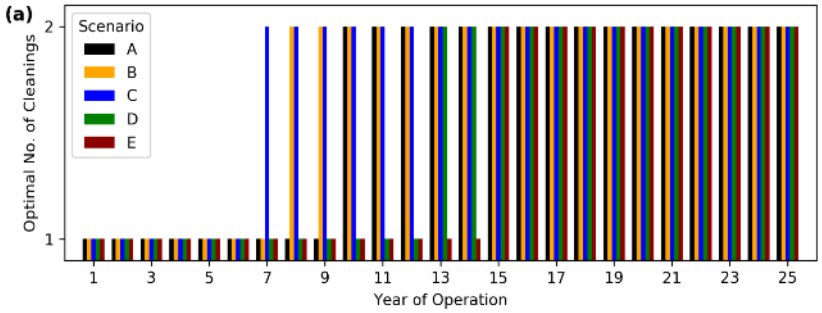
Site Selection
Plant Design & Construction

L. Micheli, E.F. Fernández, and F. Almonacid, Under Review.

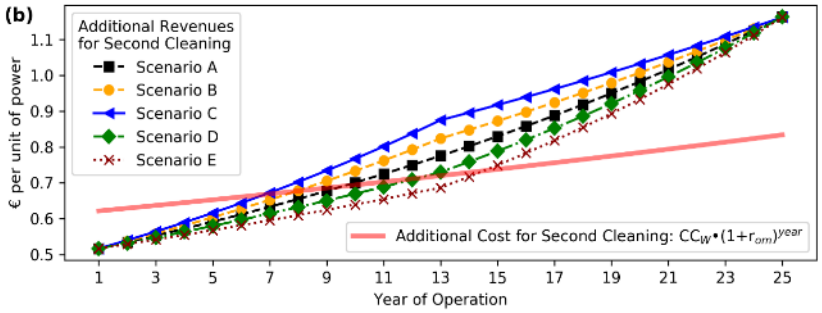
Methodology: Degradation



Five degradation scenarios were modelled, all resulting in 24% degradation loss after 25 years.

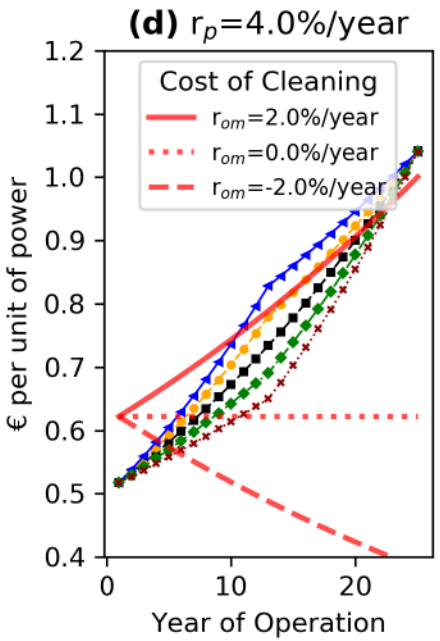


The switch from a 1- to a 2- cleaning scenario occurs in between years 6 and 15.



The lower the degradation, the sooner the switch.

Results: Yearly Cleaning Optimization



Results: Yearly Cleaning Optimization