INDUST WORKSHOP 2019
APPLICATION OF SOILING MEASUREMENT TO IMPROVED YIELD PRediction AND CLEANING OPTIMIZATION

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Intersolar 2019 INDUST Workshop

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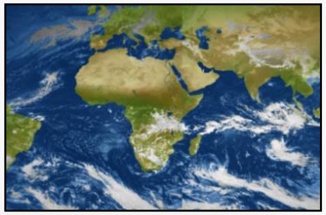
Introduction

The effect of dust particles on reflectance

Soil/ Effects

Type of soiling
- inorganic, organic, natural, anthropogenic, particle size and –form, etc.
- Standard dust (SAE j726, ISO 12103-1, DIN 400 50-9)

Consequences
- Performance loss due to scattering and absorption
- Mechanical stress, corrosion



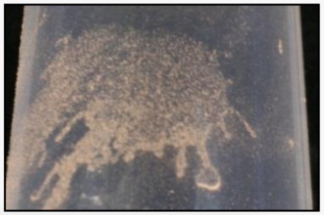
Climate / Location

Environmental impact
- Air contamination, land coverage, relief, etc.
- Wind, temperature and humidity

Glass / Coating

Application technics
- Subsequent on the substrate
- In production

Functionality
- Hydrophilic
- Hydrophobic
- Photocatalytic



Testing / Modelling

Functionality
- Characterization of properties
- Measurement of reflectance
- Reproducible soiling method (dry, under dew conditions, ..)

Durability
- UV, Temperature, Humidity
- Pollutants (e.g. salt)

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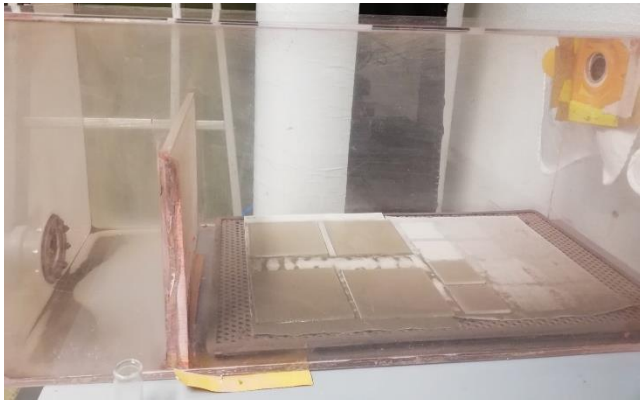
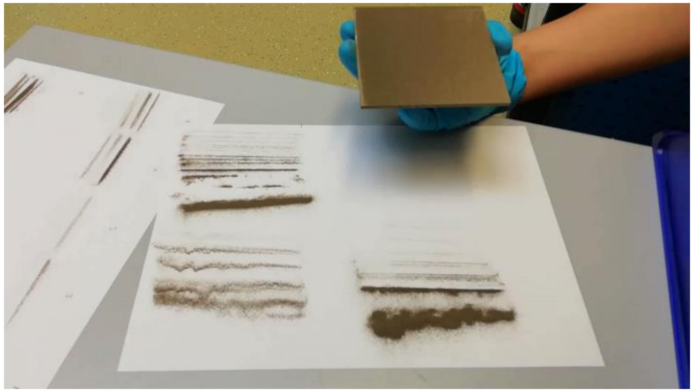
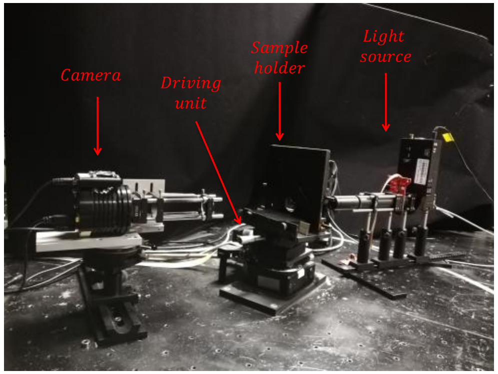
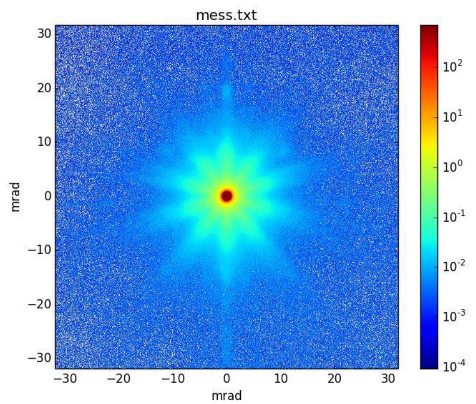
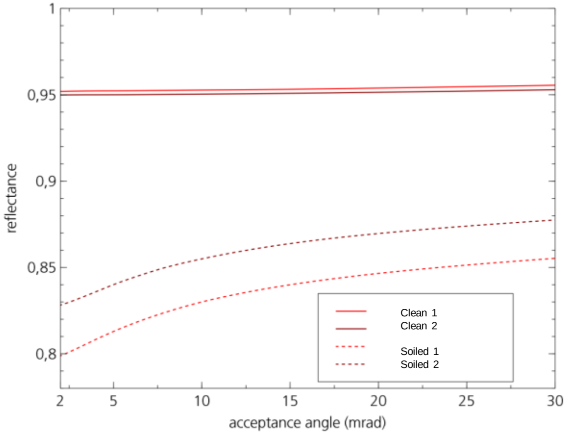
Soiling of materials – Lab tests at Fraunhofer

→ Artificial soiling allows homogeneous and comparable soiling tests







→ Assessment of scattering distribution and specular reflectance with VLABS

Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center
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Modelling of attenuation due to soiling and ist effect on reflectance

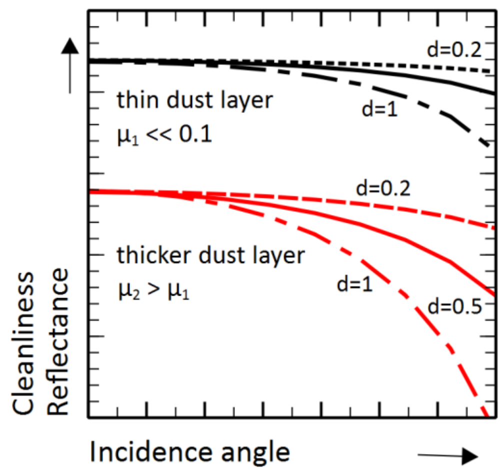
- Soiling reduces reflectance
- → Measurement with VLABS
- Modell based on Lambert-Beer

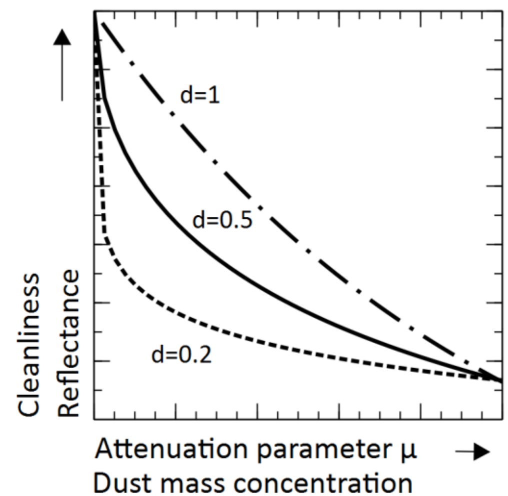
$$I(x) = I(0) \cdot \exp[-(\alpha x)] \sim |E(x)|^2$$

$$R_{s,soil} \sim \exp[-(\frac{2\ \mu}{\cos\theta_i})]$$

$$C_s(\lambda,\theta_i,\varphi) = \frac{R_{s,soil}(\lambda,\theta_i,\varphi)}{R_s(\lambda,\theta_i,\varphi)} = \exp[-(\frac{2\ \mu}{\cos\theta_i})^d]$$

- → Incidence angle dependent reduction of reflectance
- → Near Specular reflectance
- → Reduction of solar yield





A. Heimsath, „The effect of soiling on the reflectance of solar reflector materials - Model for prediction of incidence angle dependent reflectance and attenuation due to dust deposition", SolMat 2019

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Instruments for field measurements

Portable reflectometer and on-site monitoring

© PSE /Fraunhofer „pFlex"

© D&S „15-R-USB"

- Measurement of cleanliness with hand held mobile device in the field
  - pFLEX
- Automatic independent site monitoring
  - AVUS
  - Other new instruments

→ The AVUS instrument monitors cleanliness, lowmaintenance efforts

Instruments for field measurements

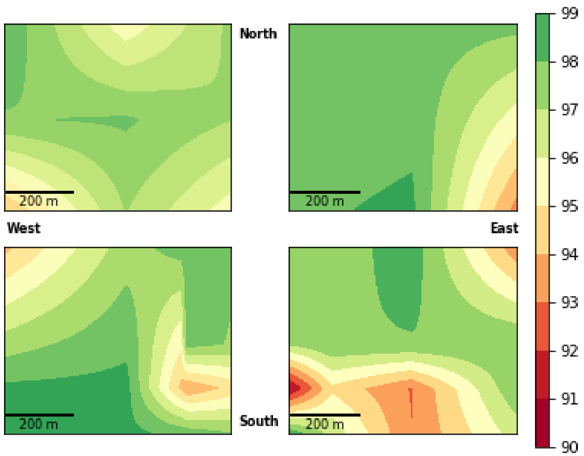
Portable reflectometer and on-site monitoring

Data collection campaign:

- Data from Andasol3 Power plant were collected
- Data campaign performed in November 2018
- AVUS Data campaign 2017, hour soiling data for a CSP plant was monitored

Findings:

- Spatial and time soiling characterization of the solar field
- Characterization of new cleaning technologies



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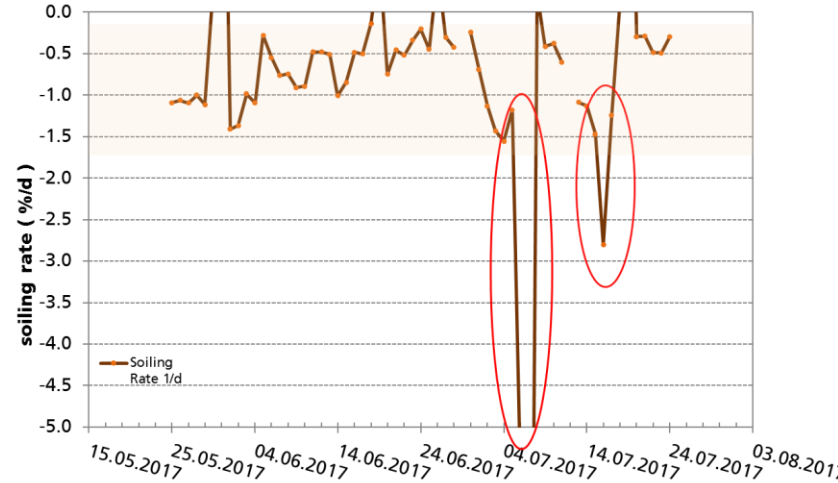
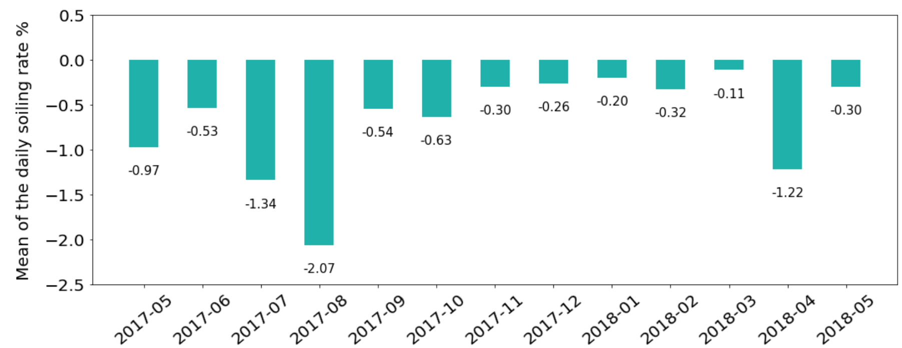
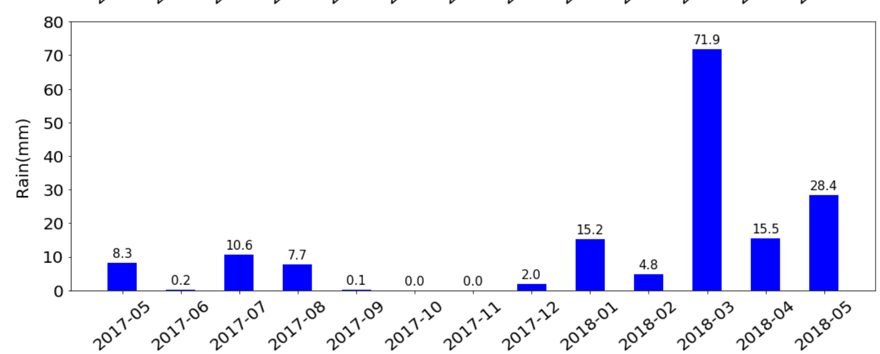
Methodology
Soiling and Meteo. Data



- **One year** measurement on a CSP site (**temporal distribution**)



- **Spatial distribution** of the soiling through three installed reflectometers



- **Rain** and **DNI** measurement of the same time period

Measured soiling rate from the automated reflectometer AVUS Heimsath *et al.*, 2018

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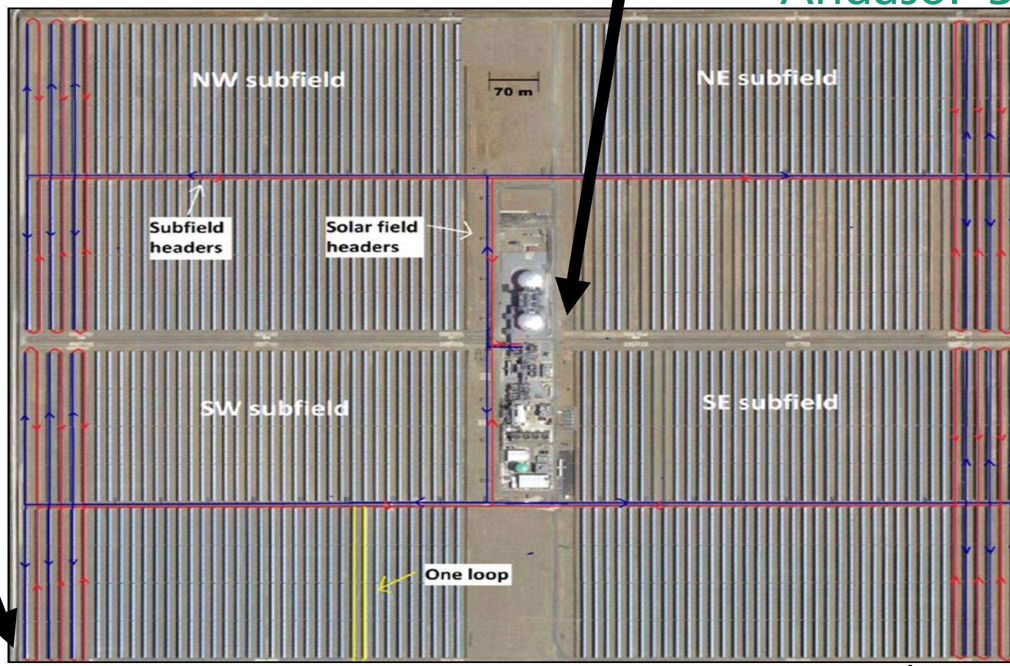
Methodology
Soiling Distribution

Reflectometer 3

Reflectometer 1

Andasol 3

Reflectometer 2



Andasol 1

Google maps

Andasol 2

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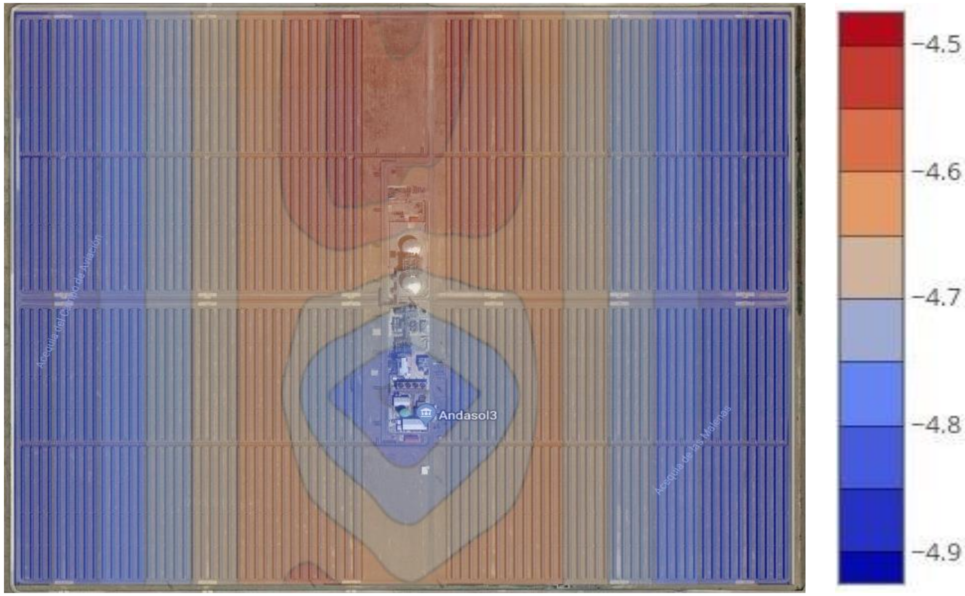
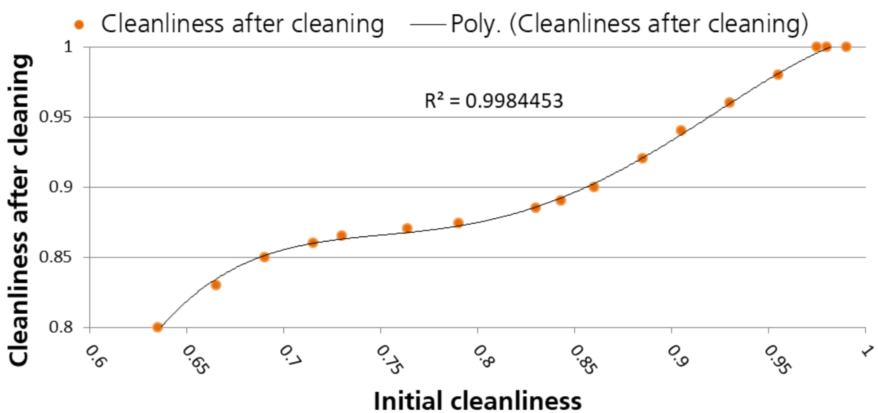
Methodology
Soiling Distribution – Exemplary Day



Aerial image of the solar field and the average soiling rate distribution across the field on 05.04.2017 (%)

Methodology
Modelling of Cleaning Trucks

- Brush Cleaning -> restore cleanliness to 98.5%
- Pressurized Water Spray -> Cleanliness depends on the initial Cleanliness



Cleanliness after cleaning as a function of initial cleanliness according to the **test results** ©ECILIMP

Cleaning trucks of PTC; A: Brush cleaning B:pressurized water spray ©Ecilimp

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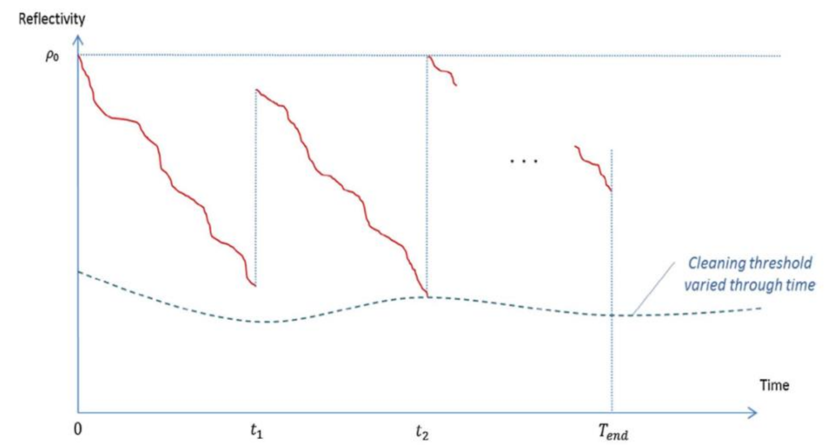
Methodology
Variable Cleaning Threshold

- The cleaning threshold varies based on:
  - Accumulated DNI*cos(θ_z) of next day
  - Rain forecast greater than 6mm for next day
- The loop with **lowest cleanliness** has priority to be cleaned.
- Brush cleaning is employed after extreme reduction in cleanliness (soiling rate > 10 %).



Source: Truong Ba et al. Optimal condition-based cleaning of solar power collectors. Solar Energy 2017

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Methodology
Modelling of Cleaning Strategies

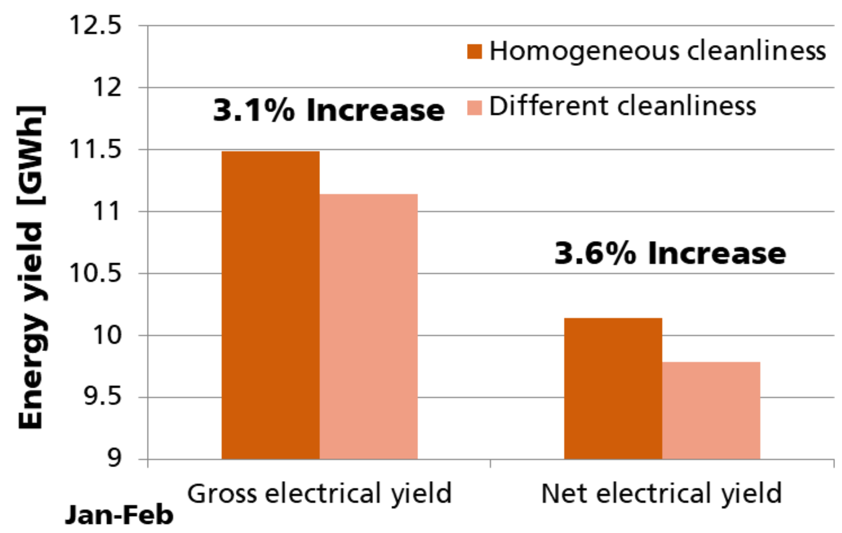
- Taking into account the operational limitations
  - Water tank refilling time
  - Distance between loops
- Investigating the benefits of real time monitoring of the mirrors cleanliness

Cleaning strategy	Description
Fixed interval (reference)	Cleaning at fixed intervals
Cleaning threshold	Cleaning only when a cleanliness threshold is reached
Variable cleaning threshold	The cleanliness threshold for cleaning varies according to the DNI & rain forecast

Results
Average Field Cleanliness vs. Loop Cleanliness

	Annual DNI [kWh/m²]	Annual solar gain [GWh]	Annual gross yield [GWh]	Annual net yield [GWh]	$\overline{\eta_{SF}}$
Homogeneous cleanliness	2354.52	531.74	191.12	171.53	45.4%
Loop wise cleanliness		522.32	187.63	168.16	44.6%
Difference	-	**1.80%**	**1.86%**	**2.00%**	**1.80%**

- Distribution of the cleanliness must be taken into account for accurate simulation
- It plays even a bigger role especially during the high soiling period



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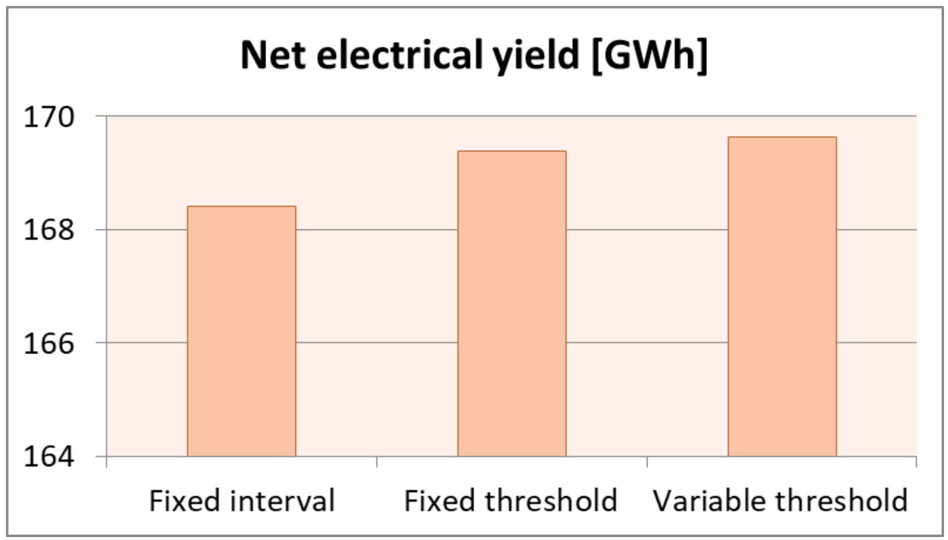
Results
Optimized cleaning strategy

In all three strategies, the annual average field cleanliness is 0.93

	Fixed interval	Fixed threshold	**Variable threshold**
Number of cleaning trucks	3	3	**2**
Water consumption [m³]	28800	25700	**23400**
Levelized cost of cleaning [¢/kWh]	0.265	0.258	**0.199**
		-10.77%	**-19.88%**
		-2.7%	**-25%**

- Optimized cleaning strategy can save up to **20%** cleaning water
- The levelized cleaning cost is reduced by more than **25%**
- Additionally, the annual **electrical yield increased** which leads to additional **LCOE reduction**



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Conclusion

- The developed tool chain allows for detailed **optimization** of operating and cleaning strategies
- **Distribution of the cleanliness** in the solar field affects the outlet HTF temperature significantly
- A more **homogeneous** distribution of the cleanliness **increases the solar gain**
- A detailed **monitoring** of the cleanliness allows for a better cleaning schedule
- Cleaning strategies based on cleanliness threshold lead to an optimized cleaning process especially if **rain and DNI** forecasting is used

Thank you for your attention!

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Minimized water consumption in CSP plants
MinWaterCSP

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