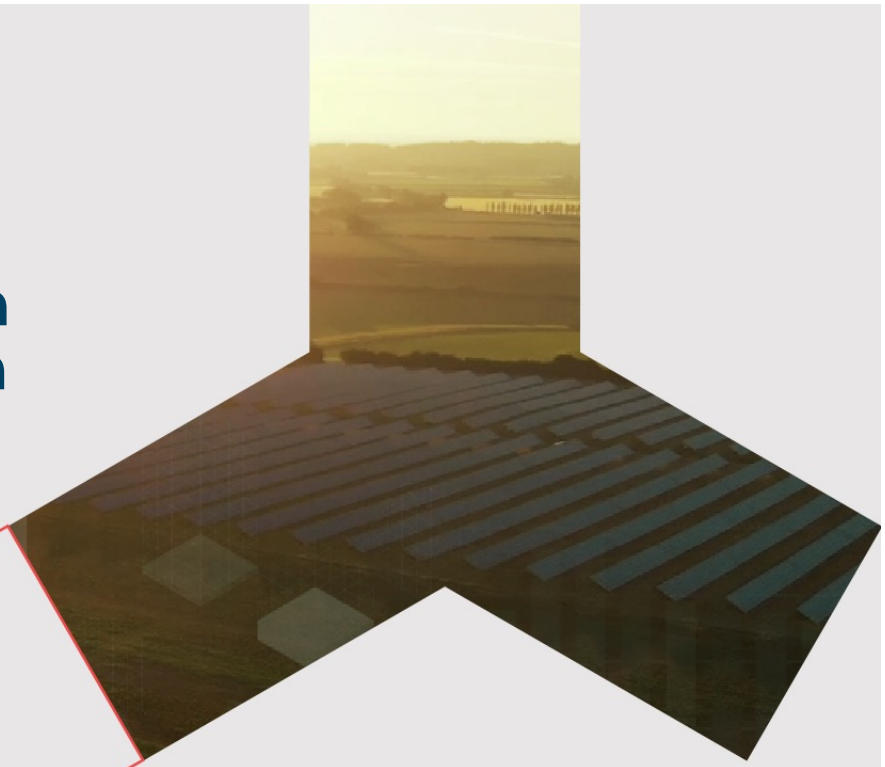
Estimation of Soiling Loss in Utility-Scale PV Plants from Production Data



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PV Performance Modeling Workshop
May 8, 2024

Agenda

1

Soiling Loss Assessment

Importance

Methods

Challenges

2

Use Case

3

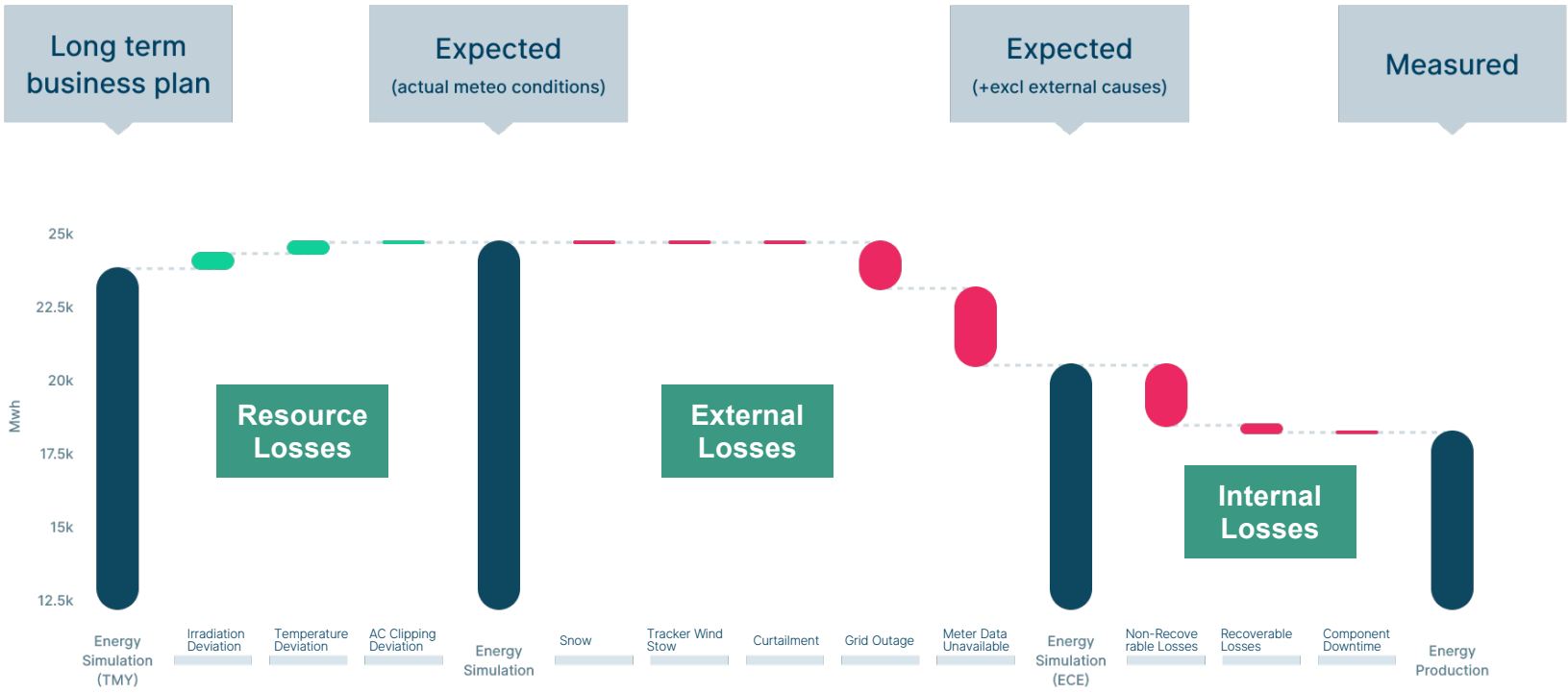
Soiling Estimation using Dynamic Internal Reference

4

Conclusions

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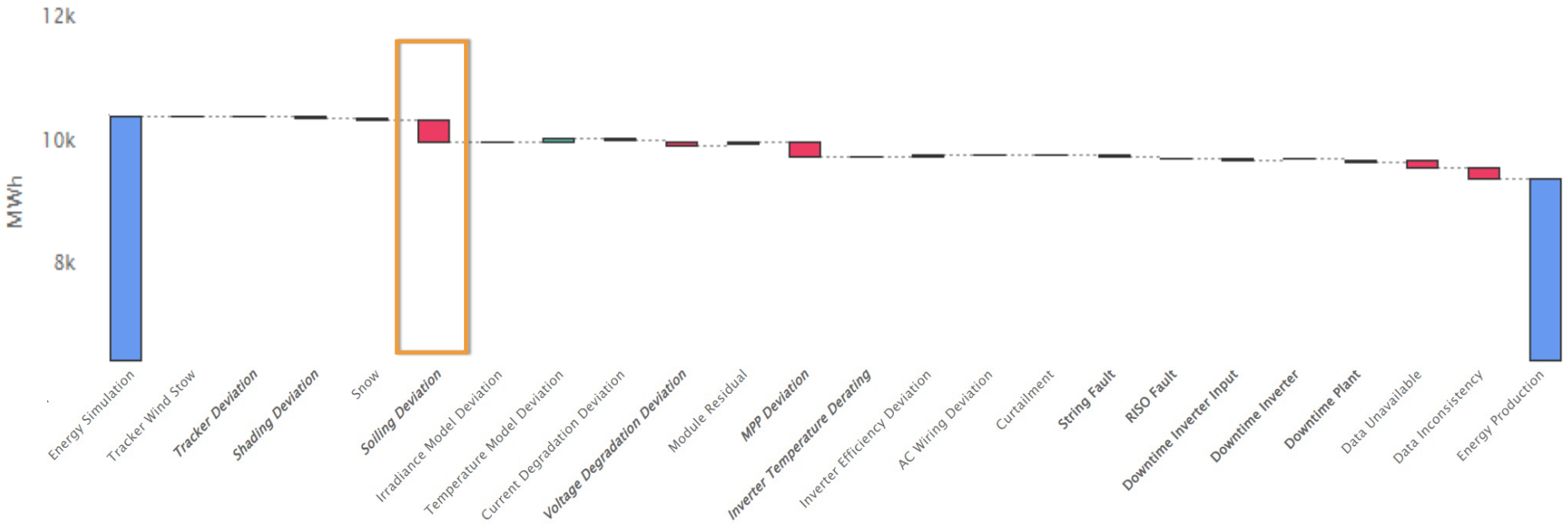
Advanced Analytics: breaking down the losses



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Waterfall analysis – unexpected losses

- Deviations are coming from 3E's Analytics
- Identification of unexpected losses that occurred during plant operation
- Recoverable categories are displayed as **bold**



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Importance of soiling loss assessment

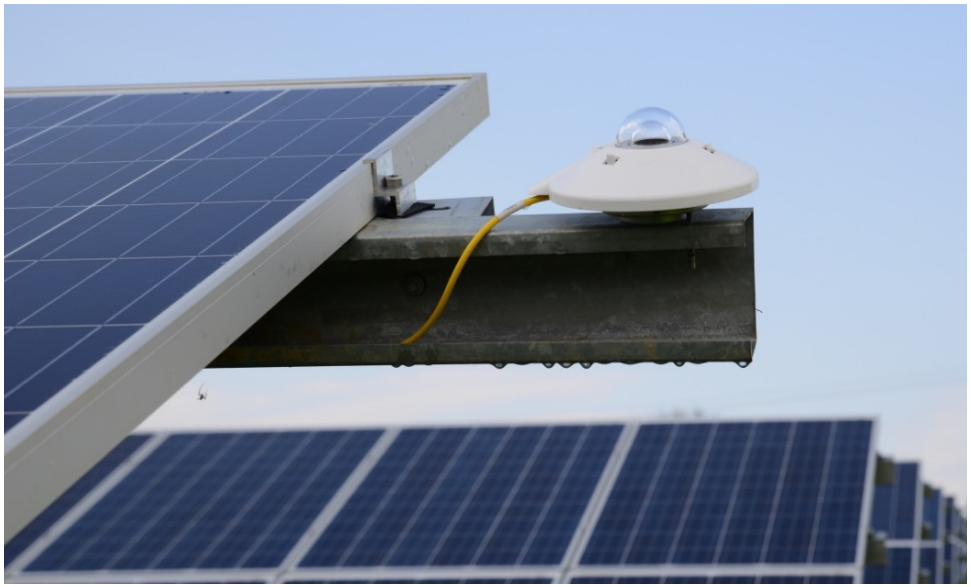
- In average ca. 50% of total recoverable performance loss
  - What loss is due to soiling?
    - Cleaning optimization
  - What loss is *not* due to soiling?
    - Solve other problems
- Hard to assess accurately
  - Only a few %
  - Varies from day to day
  - Varies from array to array, also within plants

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Soiling Loss Assessment

Existing methods

- Using irradiance as reference
  - Fixed Rate Precipitation (FRP) model
  - Stochastic Rate & Recovery (SRR) analysis



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Soiling Loss Assessment

Existing methods - Challenges

- Using irradiance as reference
  - Pyranometer must be clean every day
  - Even with high quality day, noise is significant
  - Hard to distinguish from degradation, …
- Using soiling sensors
  - Non-uniform soiling → multiple sensors
  - Cleaning schedule → more sensors
  - Deviating soiling behaviour
  - Deviating cleaning
  - Extra hardware, data collection, costs



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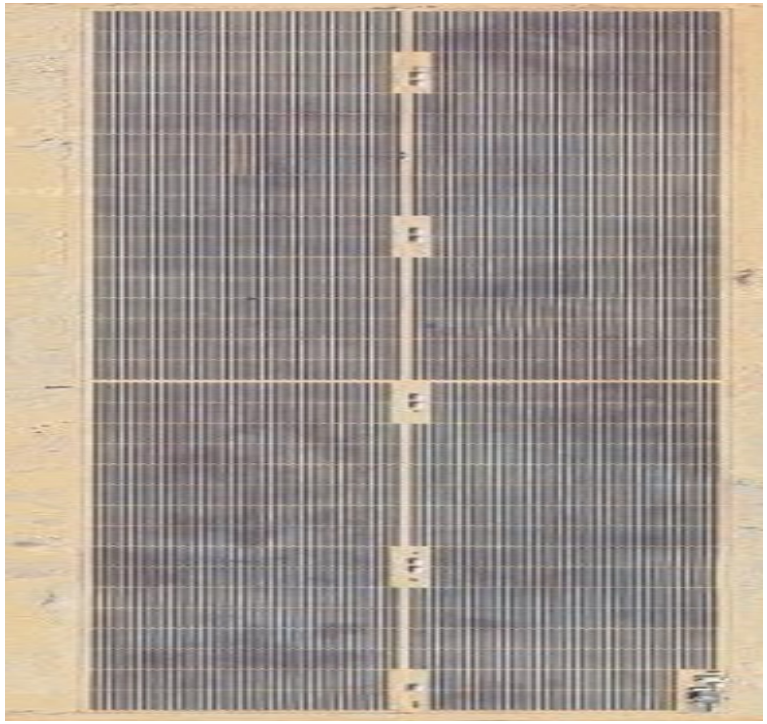
Use Case



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Use Case

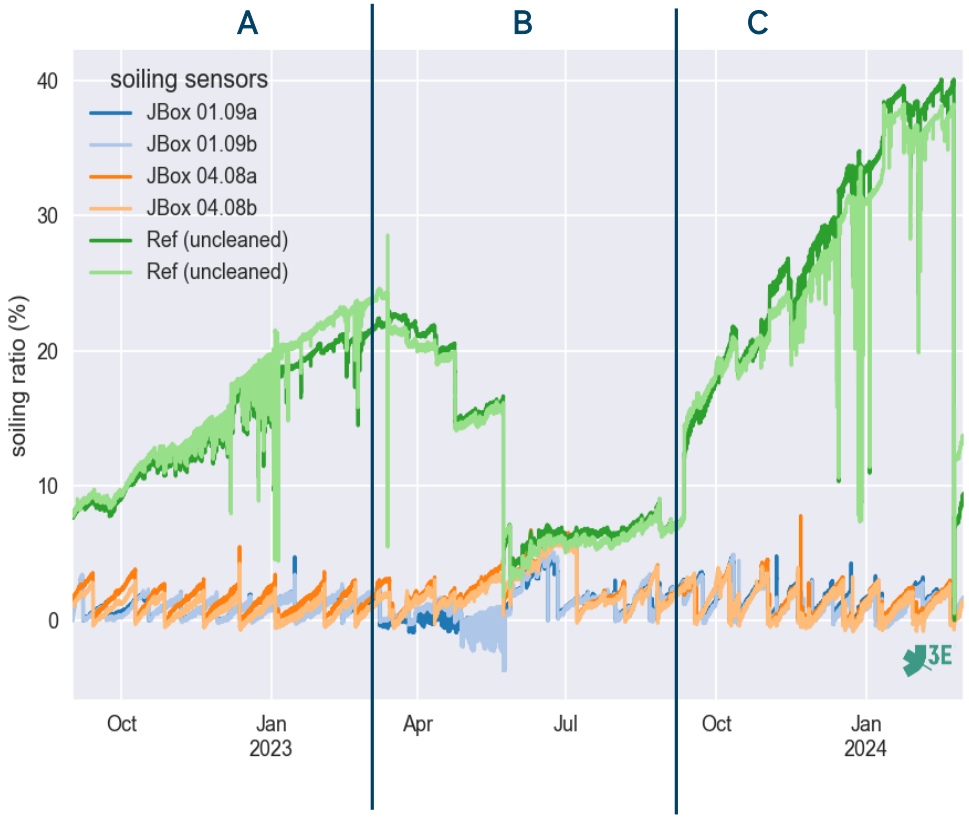
- 30 MW utility-scale plant
  - Single-axis trackers
  - Desert, lots of clear sky, almost no rain
  - Cleaning schedule, no tickets
  - High data availability, virtually no component downtime
  - 6 in-plane pyranometers (+ horizontal)
  - 3 Soiling sensors (at different locations)
  - Power at max AC capacity during Spring & Summer
- Demonstration of soiling assessment
  - Data at junction box level
  - Soiling sensors are used for validation



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Soiling Sensors

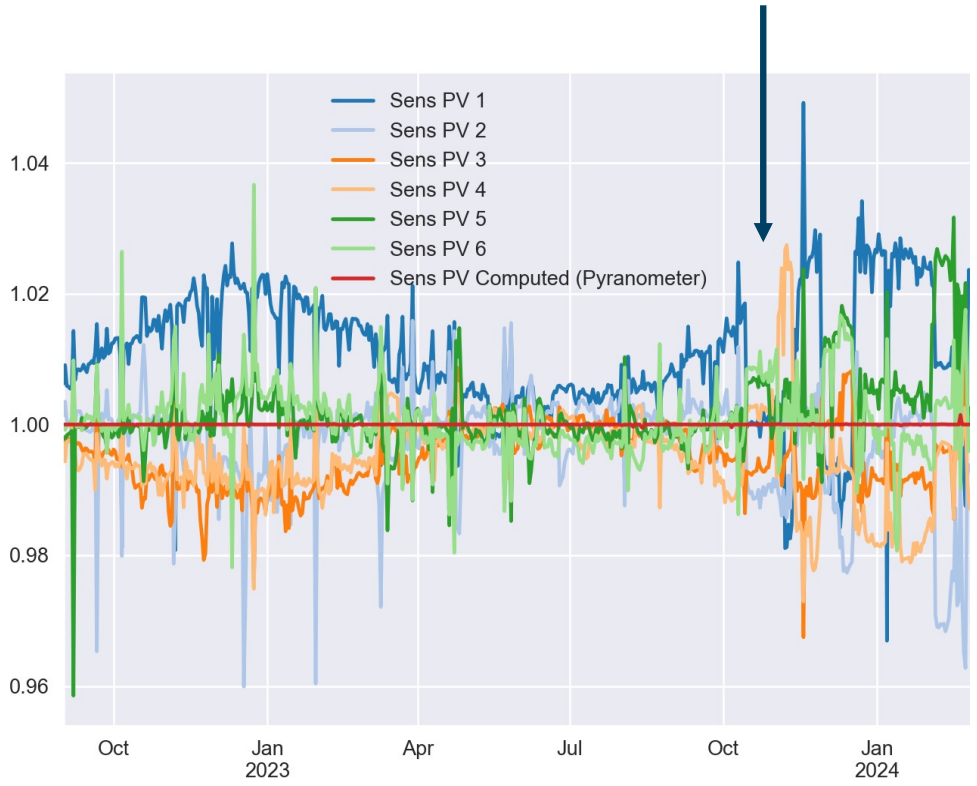
- 3 Kipp&Zonen Dust IQ soiling sensors
  - Each sensor has 2 signals (redundancy)
- One uncleaned sensor → Ref
  - Soiling ratio up to 40%
  - Soiling rate varies over time
- Two cleaned sensors
  - Cleaned together with PV modules
  - Interval of 3-4 weeks during A and C
  - Some longer intervals during B
  - Soiling ratio mostly between 0 and 3%



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Pyranometers

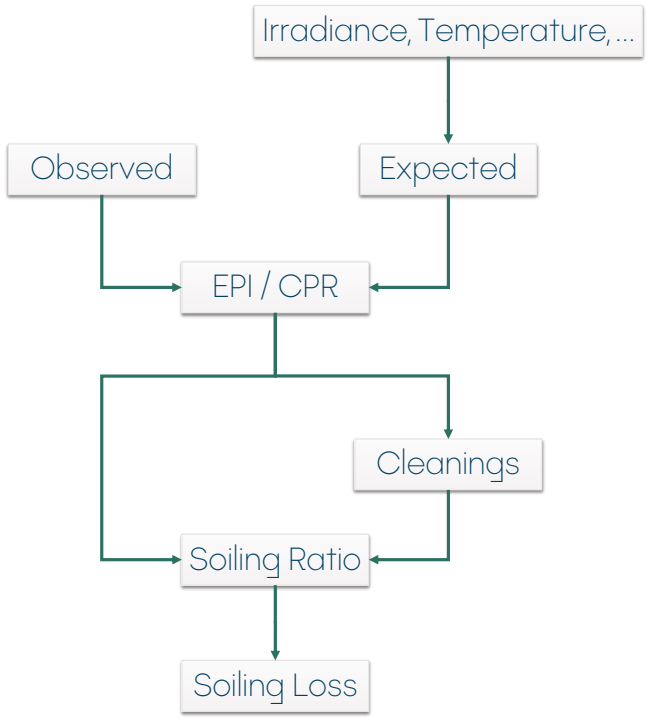
- Individual pyranometers show significant variance compared to average:
  - Up to ca 1% bias
  - Up to ca 2% seasonality
  - Up to ca 3% short-term bias shifts
    - Most problematic
  - Up to ca 4% spikes



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Soiling estimation using Irradiance as reference

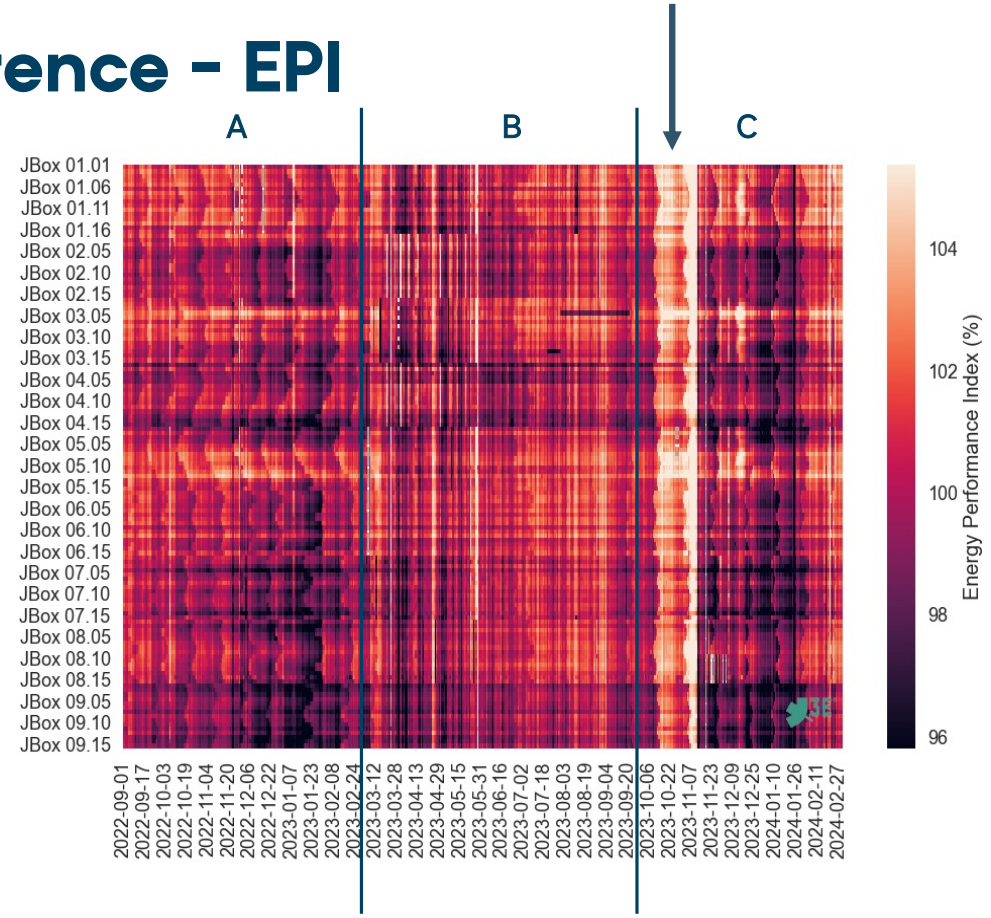
- Energy Performance Index (EPI)
  - Observed / Expected
  - ~ Corrected Performance Ratio (CPR)



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Using irradiance as reference – EPI

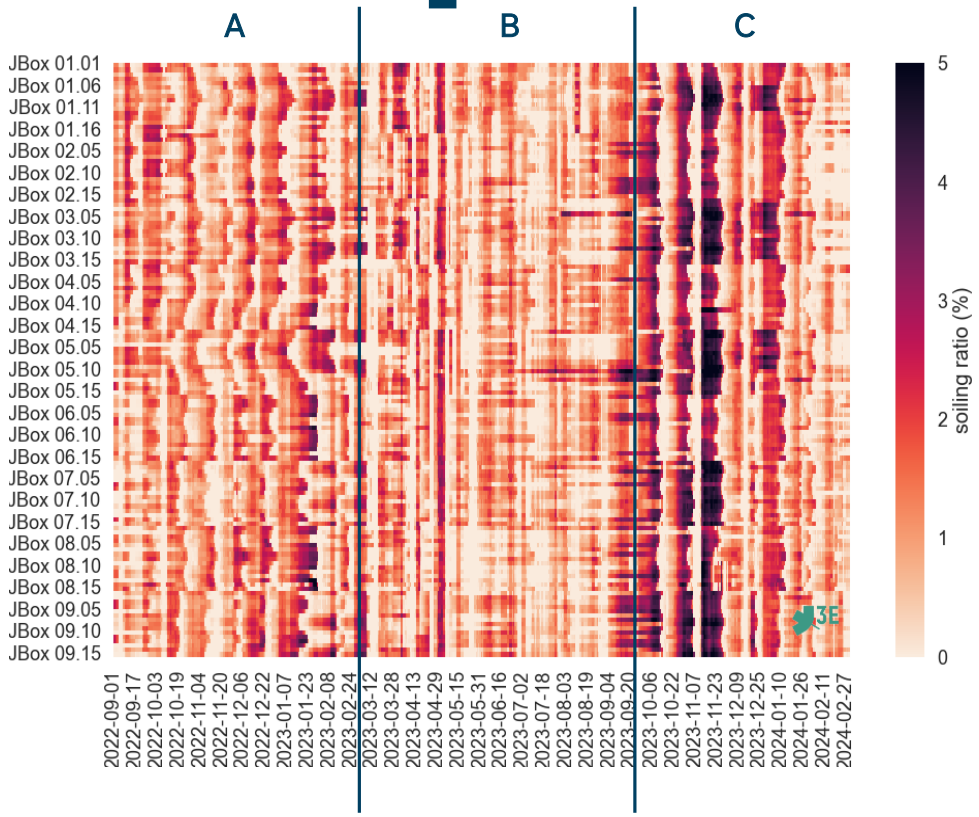
- Episodes A and C
  - Clear soiling and cleaning pattern
- Episode B (Spring & Summer)
  - Production often at maximum capacity
  - No clear soiling and cleaning pattern
- Noise reduction
  - Outlier removal
  - Significance weighting
  - Robust algorithms
  - Smoothing over few days
- Still some suspicious values



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Using irradiance as reference – Soiling Ratio

- Estimation from EPI
  - Cleaning events
  - Soiling ratio
- Estimates are heavily impacted by noise in irradiance
  - When cleaning twice a year
    → smoothing over longer period
  - When cleaning every 3 weeks
    → Need for better solution



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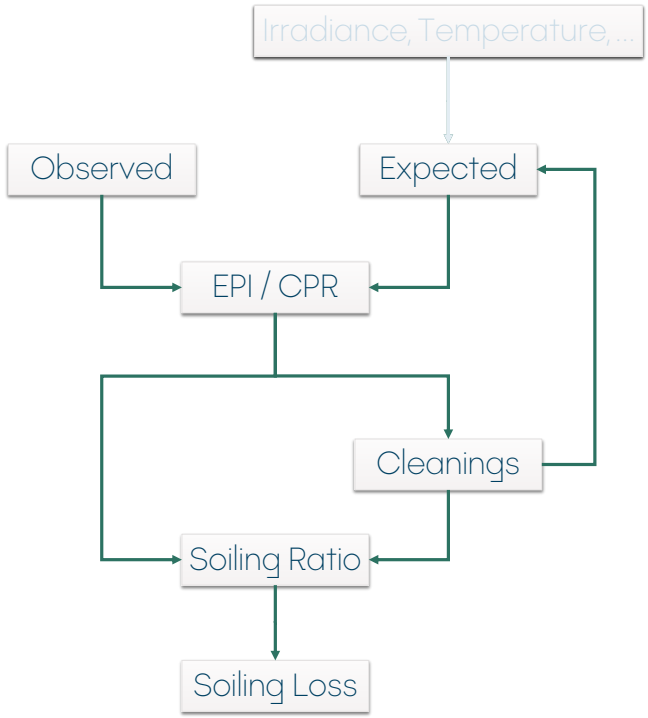
Dynamic Internal Reference method



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Dynamic Internal Reference Model

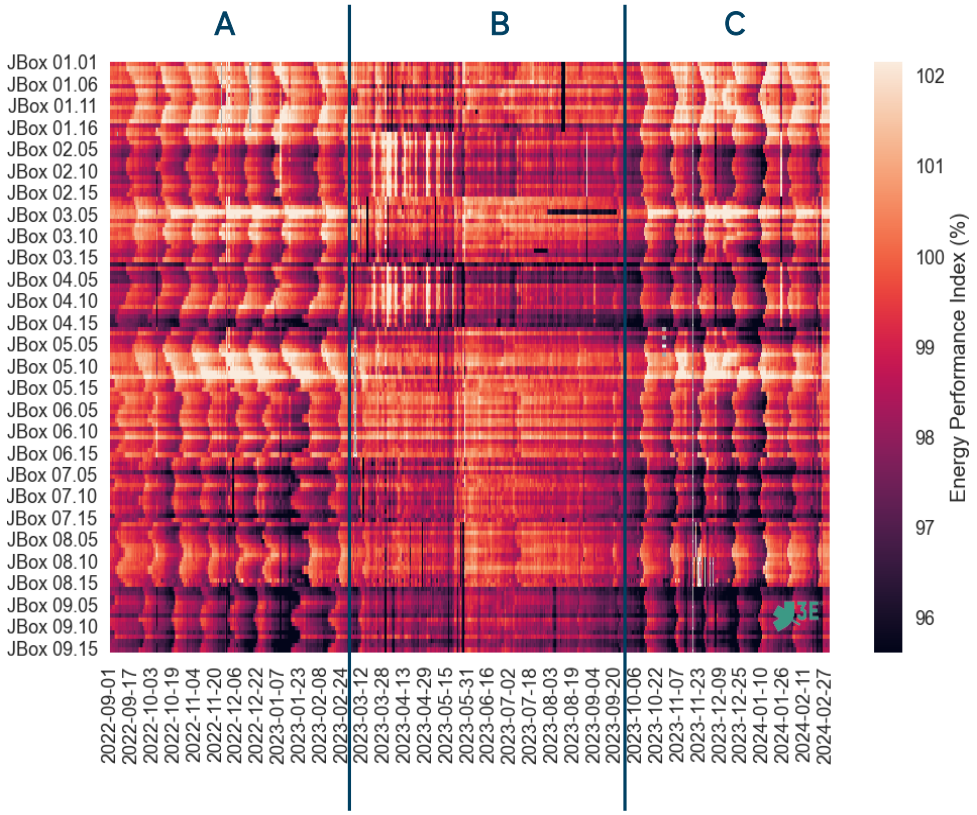
- Use cleaned arrays as reference
  - while coping with
    - Outliers
    - Non-uniform degradation
    - Days with no cleaned arrays
- Noise in irradiance has far less impact



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Dynamic Internal Reference – EPI

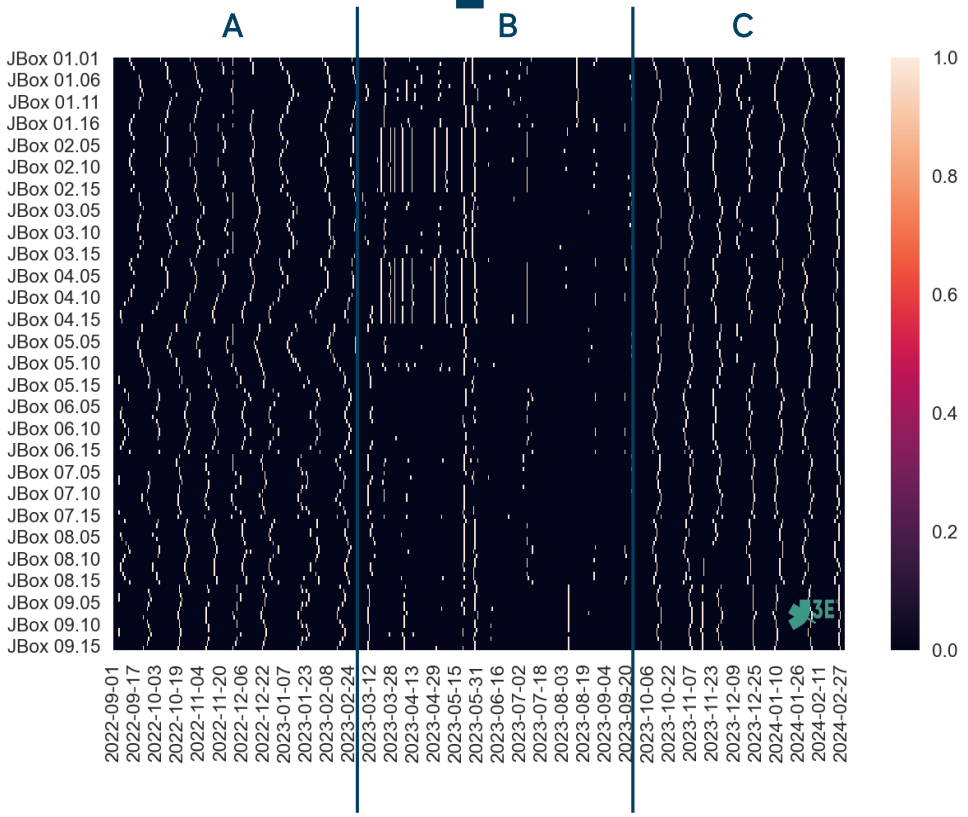
- Use cleaned arrays as reference
  - while coping with
    - Outliers
    - Non-uniform degradation
    - Days with no cleaned arrays
- Noise in irradiance has far less impact



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Dynamic Internal Reference – Cleanings

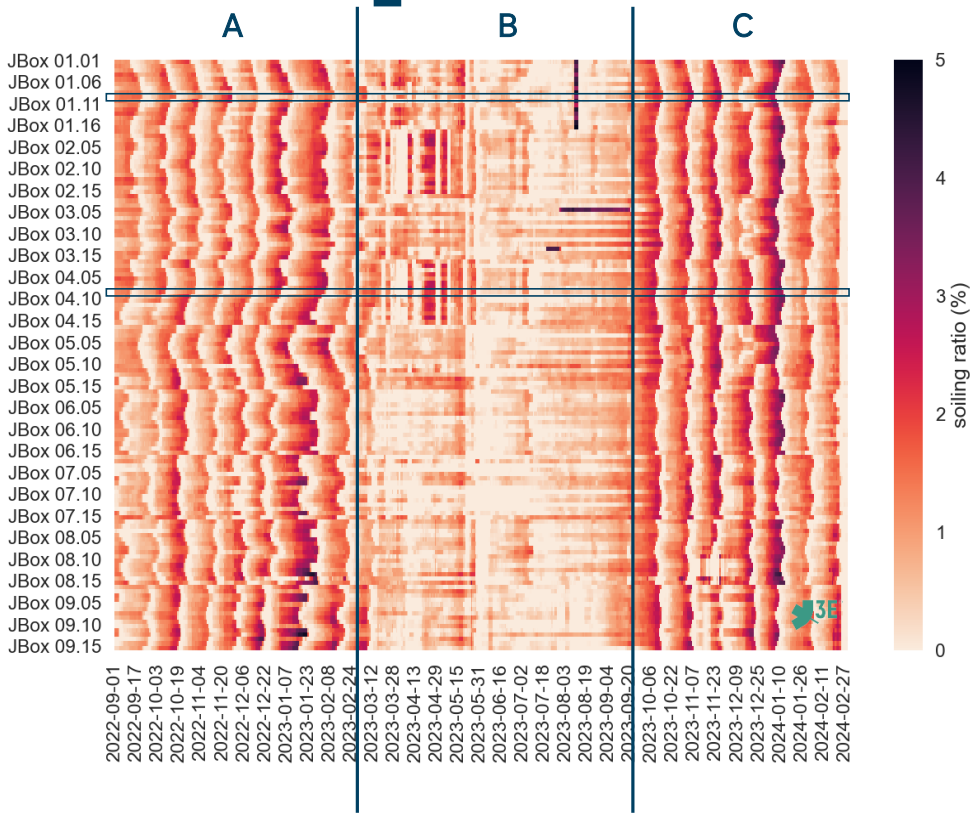
- Episodes A and C
  - Good detection of cleanings
  - Only few false positives / negatives
- Episode B
  - Power at maximum hides soiling
    - Poor detection of cleanings
    - False positives & negatives
    - Ongoing development



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Dynamic Internal Reference – Soiling Ratio

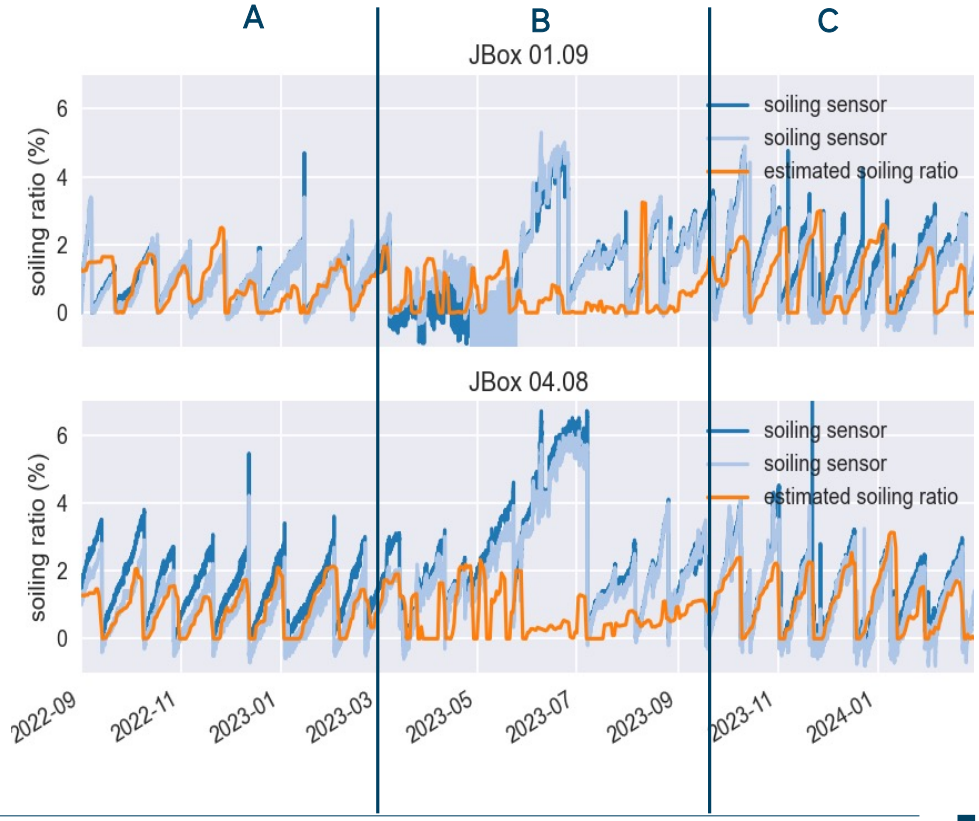
- Accurate soiling ratio estimation during A and C, coping with:
  - Inaccurate or absent irradiance
  - Non-uniform & variable soiling
  - Non-uniform & variable degradation
  - Days without cleaning
- Validation against soiling sensors



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Soiling Ratio – Validation against soiling sensor

- Mostly good agreement with Soiling sensors during A and C
- No agreement during B
  - Power at maximum hides soiling
  - Ongoing development



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Conclusions

- Accurate estimation of soiling losses is hard, even with high quality data
- Cleaning optimization of utility-scale PV plants requires accurate soiling estimation
- Dynamic Internal Reference method → Solution for utility-scale PV plants
  - Removes need for soiling sensors
  - Reduces reliance on irradiance data
  - Improves accuracy dramatically
  - Copes with non-uniform & variable soiling, degradation, days without cleaning, …
- Integrated in 3E-SynaptiQ solar monitoring & analytics platform

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3E-SynaptiQ: transforming data into revenue gain

Renewable Assets

PV Plant

1) Inverter input
2) Trackers and sensors
3) Meters

Meteorological Conditions

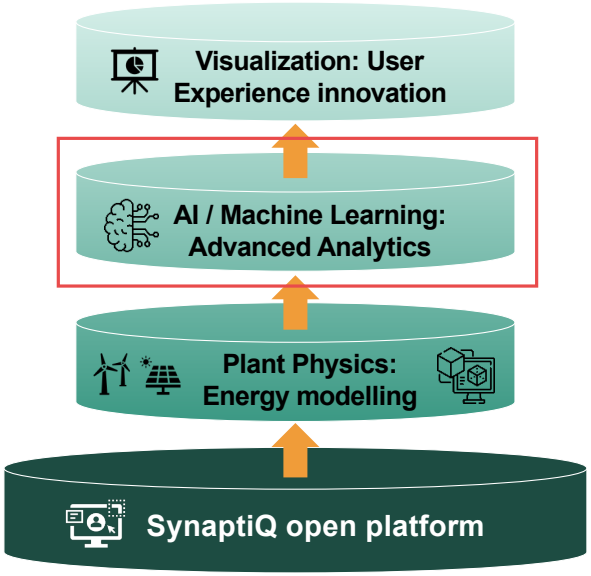
1) Meteo stations
2) Satellite data

PV Plant Design

1) Datasheets
2) Typical Meteorological Year
3) Electrical layout

Value Centred Technology

SynaptiQ Digital Twin



Customer Outcomes

Benefits

Increase Revenue

- ✓ Revenue: +4% from day one

Reduce Costs

- ✓ Manhours in APM: -70%
- ✓ OPEX: -3% .. -5%

Differentiators

- ✓ Highest level of energy loss recoverability
- ✓ Smart Alarms, ROI prioritized
- ✓ Advanced Analytics
- ✓ Fast, scalable implementation
- ✓ Seamless integration into CMMS, ERPs

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THANK YOU!

PROJECT PARTNERS

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Thank you

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