eurac research

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The role of digitalization in advanced operation and maintenance practices

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Outline

- What is O&M of PV?
- PV plant design + components
- PV plant monitoring + operations
- Plant inspection and maintenance

- The role of digitalization in O&M

Short intro about myself

- Main research topics
  - PV performance and reliability
  - Modelling + machine learning in PV and solar irradiance
  - PV sustainability and circularity
  - Experience Curves / Learning Curves for energy technologies

- Short resume
  - Senior Researcher, PV Performance + Reliability + Sustainability,
    Eurac Research, Institute of Renewable Energy, Oct. 2019 - present
  - Post-doct, Experience Curves of Renewable Energy Technologies
    Copernicus Institute of Sustainable Development, Utrecht University 2017-2019
  - PhD thesis: “Assessment of the energy performance, economics and environmental footprint of silicon heterojunction photovoltaic technology”.
    Copernicus Institute of Sustainable Development, Utrecht University, Jan. 2017

Operation and Maintenance of PV

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Operation and Maintenance of PV

- O&M aims to ensure performance:
  - Technical
  - Safety
  - Economic
- To mitigate health, safety, security, environment (HSSE) risks
- To maximize energy yield and minimize downtime
- To achieve lowest LCOE and optimal ROI

Operation and Maintenance of PV

- Early stages of utility PV development: O&M focused on corrective and preventive maintenance
- Often (sub)contracted based on fixed percentage of plant investments
- Declining system prices -> margin became narrower
- At the same time need for professionalization
- One of the movements is to apply digitalization in all O&M activities

Solar O&M activities

- Asset management
  - E.g., components, warranty and claims, insurance, spare parts
- HSSE compliance + end-of-life management
- Plant operations + monitoring
  - Performance, power plant control, forecasting, grid compliance, ….
- Maintenance and inspection
  - Preventive, corrective, predictive, extraordinary maintenance
  - Cleaning, site management (e.g. vegetation), inspection
- Revamping and repowering

Operation and Maintenance Data Sources + Streams

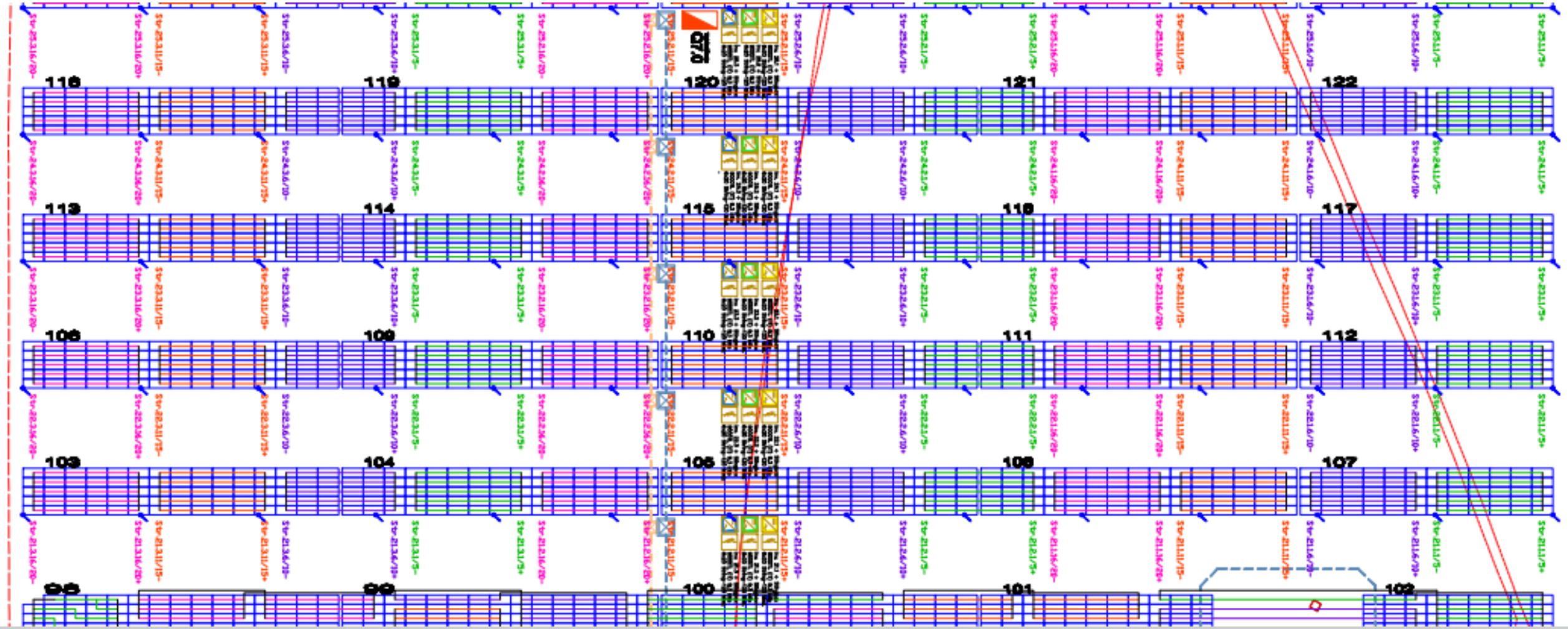
- PV plant components data + as-built documentation
  - Datasheets/specifications
  - Physical/georeferenced layout
  - Electrical layouts
- Monitoring data
  - Weather data, inverter/string/module level electrical data, alarms
- Inspection data
  - Infrared, IV-curves, EL, soiling
  - From ground or aerial surveys
- Maintenance tickets
- … And much more ….

The role of digitalization in PV O&M

- Mainly: efficiently process all these datastreams
- Also: leverage smart analysis + combinations of data
- For new insights and possibilities

- Aim: optimize O&M
  - Reduce downtime, energy loss
  - Improve O&M detection, acknowledgement, response, resolution times
  - Lower cost of O&M activities

PV plant design

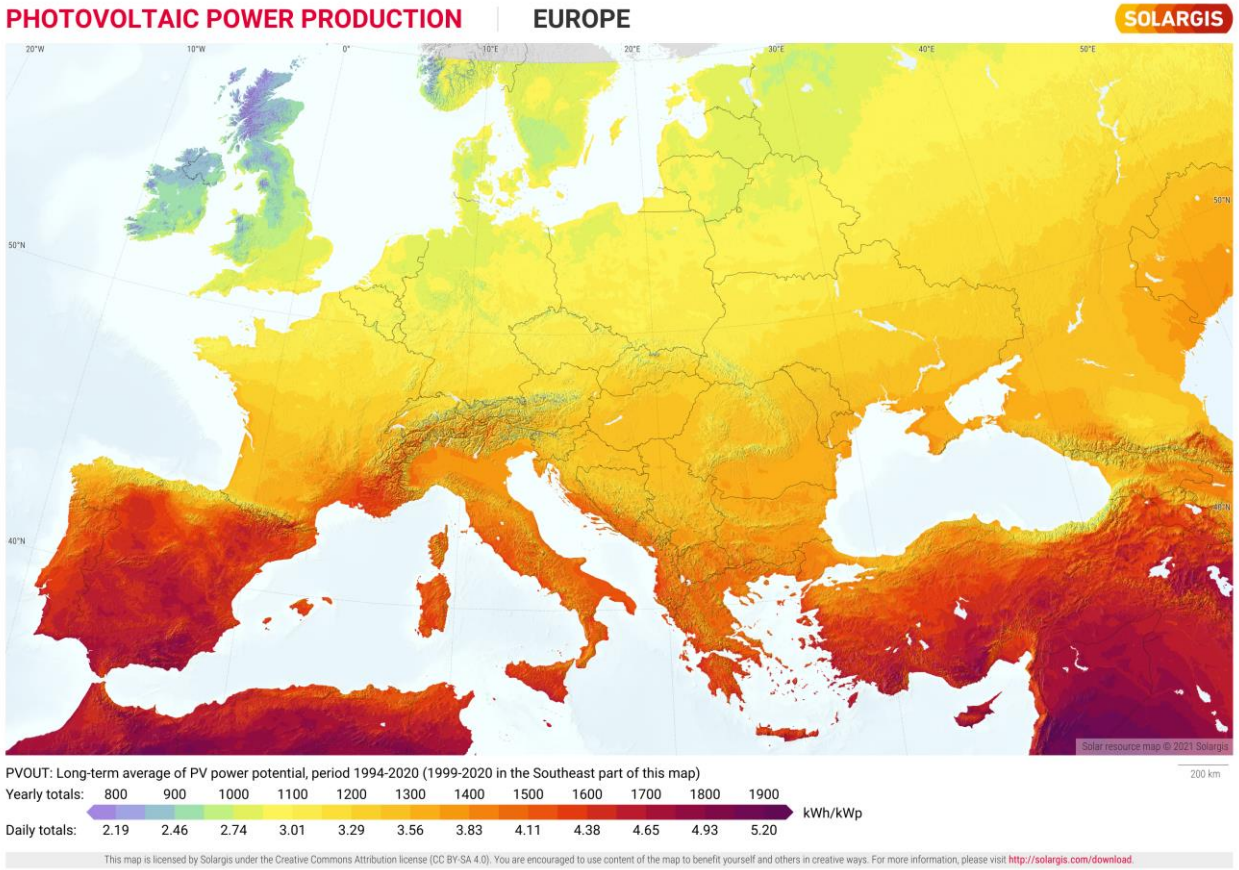


PV plant design

- From early design to engineering, procurement and construction (EPC), digital tools are necessary
- In site selection: for evaluating meteorological data
- In early design stage: for design + yield assessment
- And finally, for the engineering drawings

PV plant design

- Solar Irradiance Data + Simulations



SOLARGIS

Reuniwatt

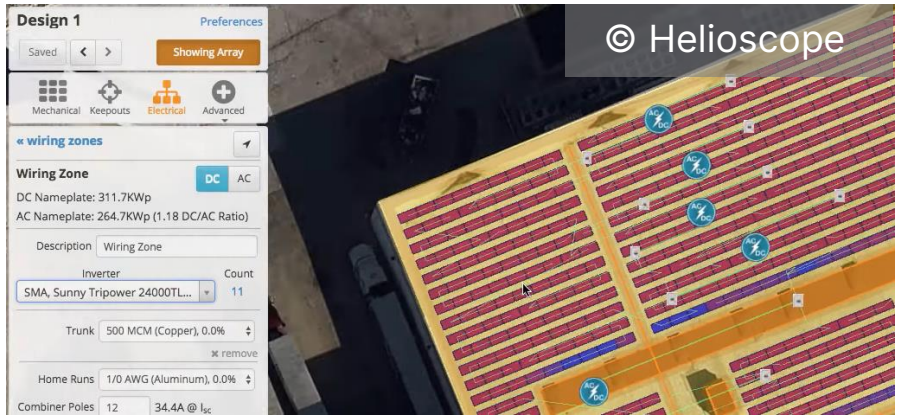
SolarAnywhere®

Meteonorm

PVGIS
PHOTOVOLTAIC GEOGRAPHICAL INFORMATION SYSTEM
European Commission

PV plant design

- Recent years saw big improvements to available tools:



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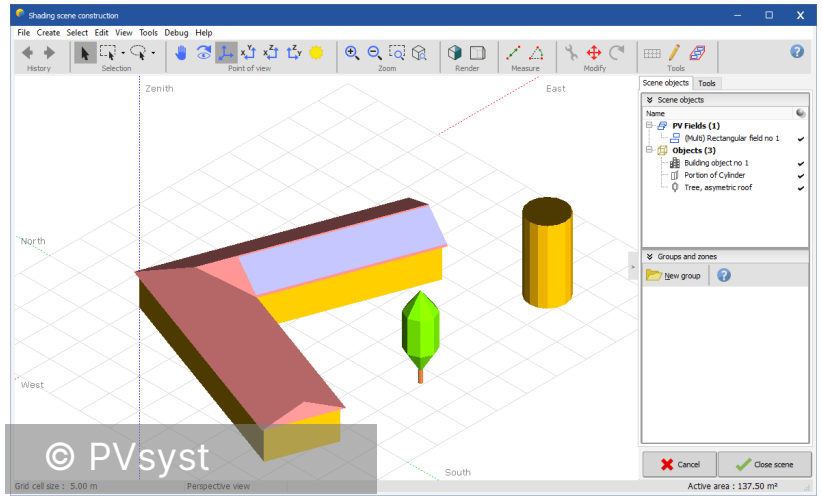

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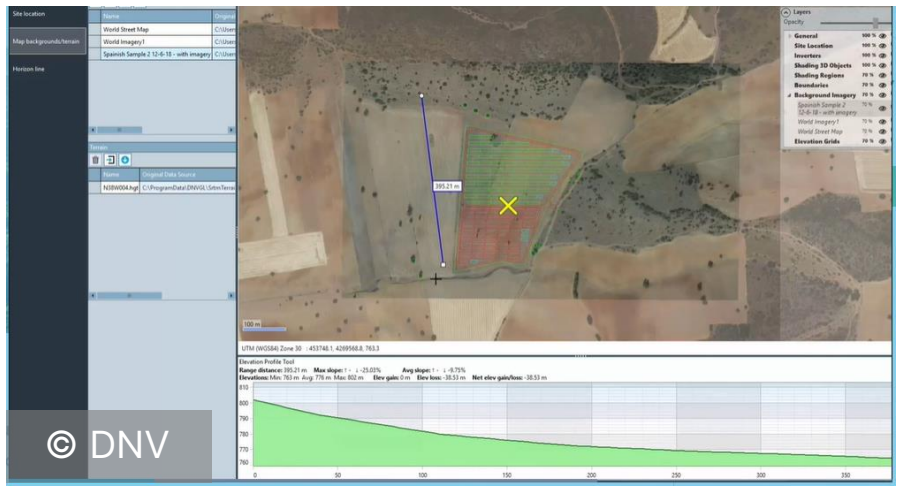
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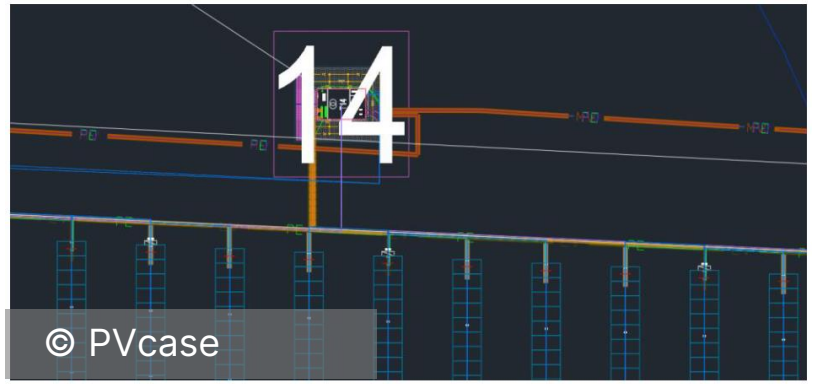

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PVsyst

PVcase

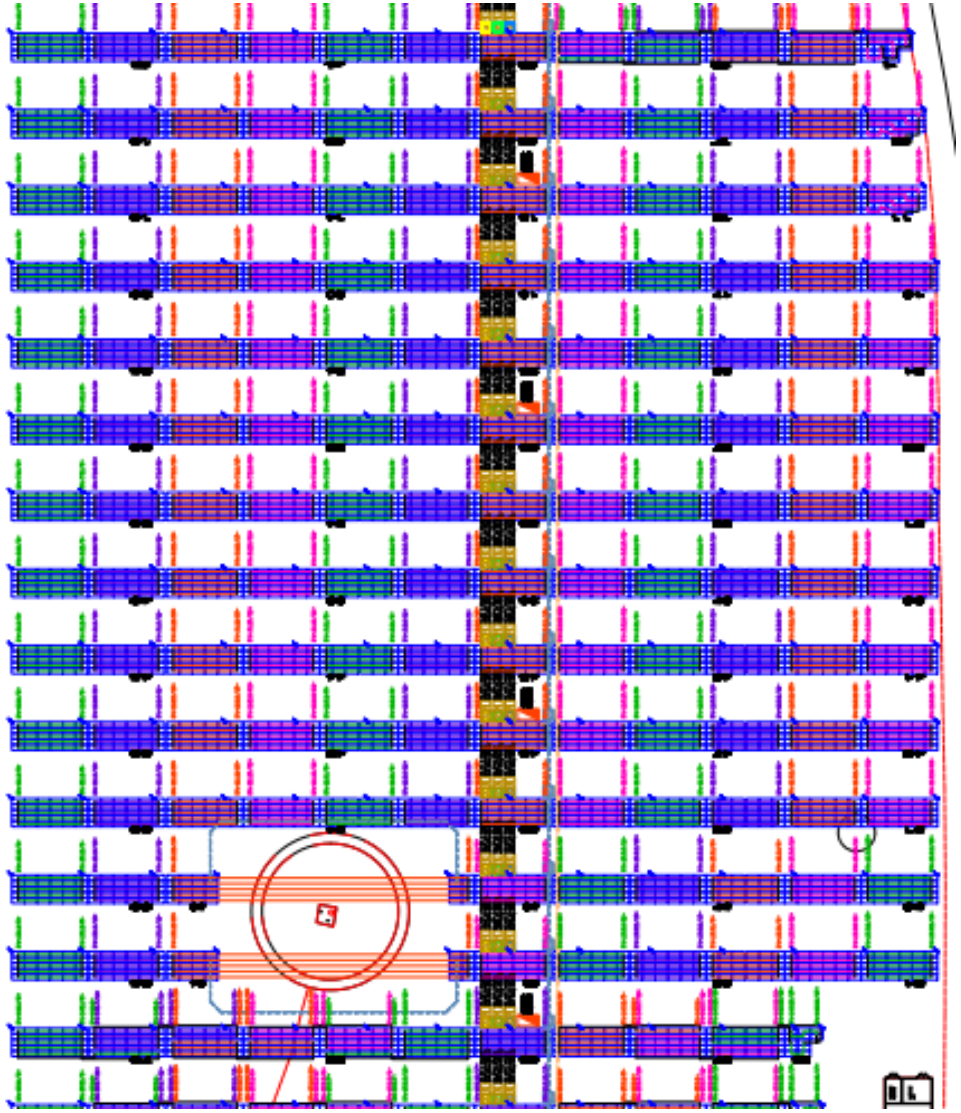
PVComplete

HelioScope

SolarFarmer
PV plant modelling
Version 1.0
DNV

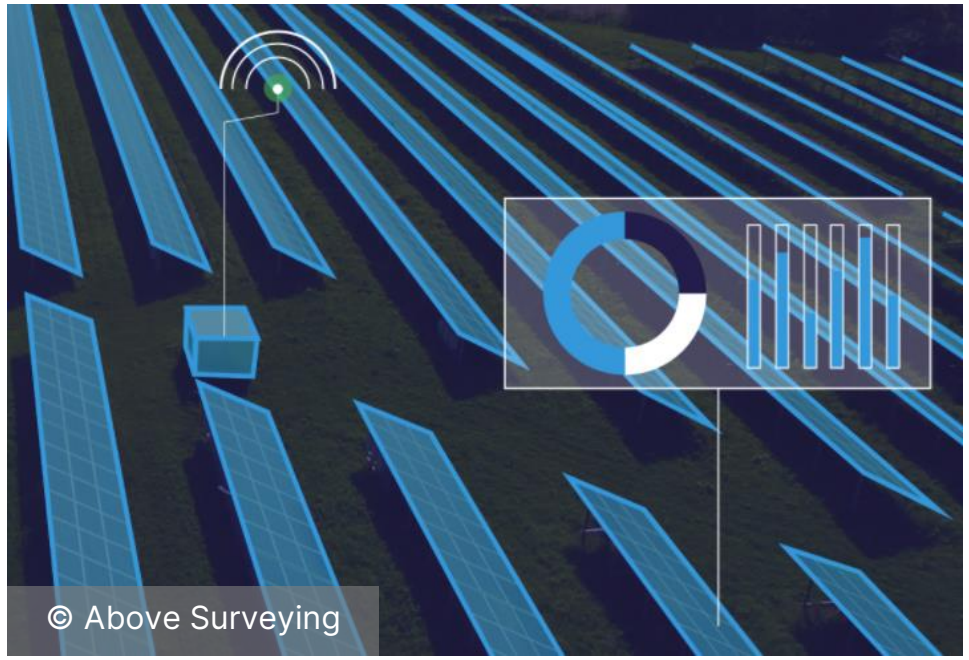
Why is this important in context of O&M

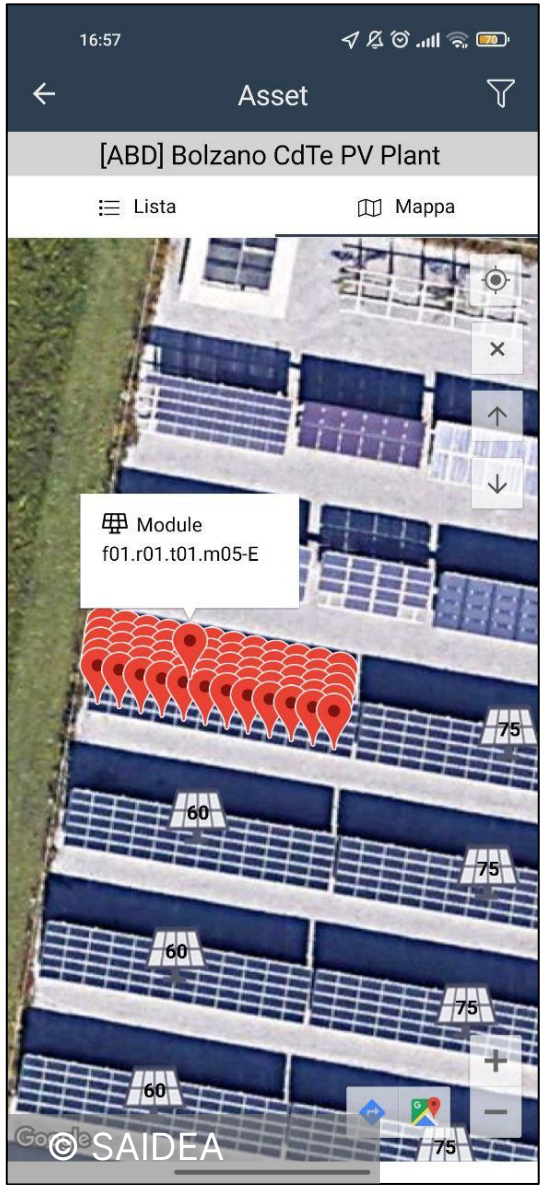
- Most O&M activities need detailed design info
- By applying integrated digitalization all data is kept
  - Physical / georeferenced layout
  - Electrical layout
  - List of PV plant components including cabling, frames, etc.
- Can be used for digital twin + georeferenced model
  - For existing systems, data can be acquired using e.g. drones to acquire 3D-data (LIDAR, photogrammetry)



Digital Twins

- Broadly apply term with different meanings
  - Digital representation of the PV plant
  - Electrical layout
  - Physical layout
  - Geolocalized
- Used for, e.g.:
  - Yield modelling
  - Fault detection
  - Asset management
  - Field inspections and maintenance





PV plant monitoring

PV plant operations and monitoring

- Performance monitoring + KPIs
- Fault detection + tickets
- Forecasting
- Powerplant control + grid code compliance

PV plant performance monitoring

- Minimally, O&M operator should track performance at plant level
- Ideally, inverter or even string level monitoring is used
- Ensure nominal operation according to a set of KPI’s
- Detect faults in operation

PV plant performance KPI's

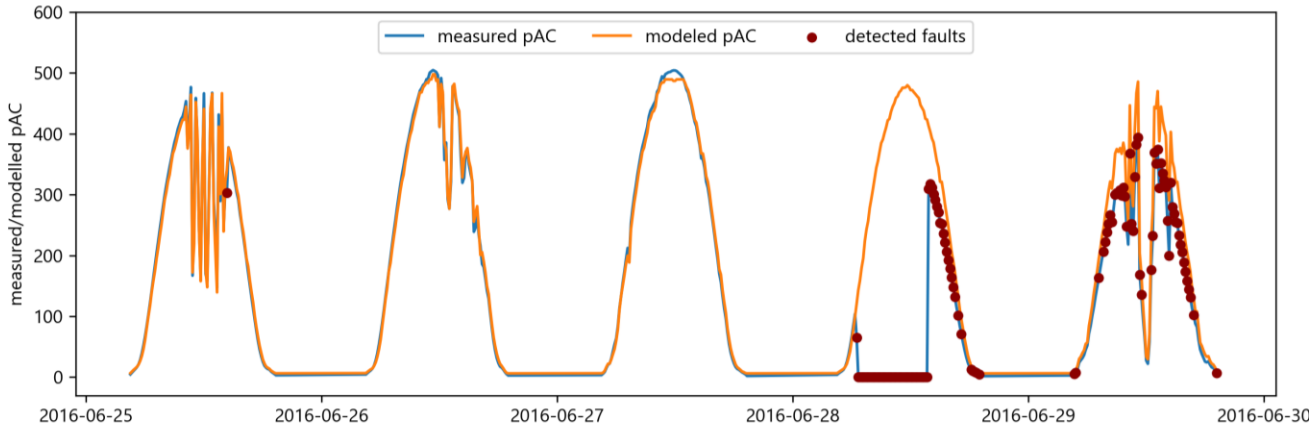
- Reference Yield $\mathrm{Y_r} = \frac{H_{POA}}{G_{STC}}$
- Specific or Final Yield $\mathrm{Y_f} = \frac{E}{P_0}$
- Performance Ratio $PR = \frac{Y_f}{Y_r}$, $PR_{tc} = \frac{Y_f}{Y_r * tc}$
- Expected Yield $Y_{\mathrm{exp}} = PR_{\mathrm{mod}} * Y_r$
- Energy Performance Index $EPI = \frac{Y_f}{Y_{\mathrm{exp}}}$
- Uptime, availability, etc.

The role of digitalization – Monitoring + Operations

- Set-up, perform, transmit and process measurement data from PV plants
- In real-time (or a.s.a.p.)
- Calculate and visualize KPIs
  - Key is to make sure operators see (only) necessary information
- Inspect data to see if plants operate as expected
- Detect Faults

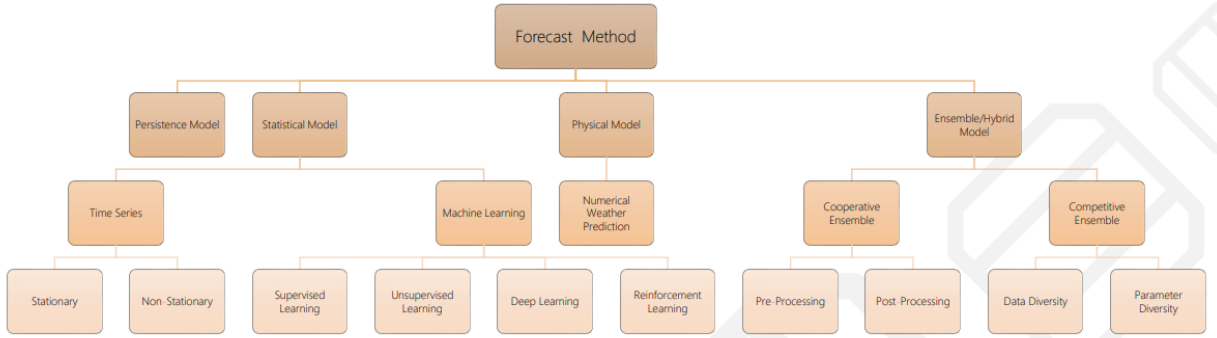
Fault detection

- Very active field in PV research
- Aim is to minimize detection and response time
- To prevent losses in revenue and downtime
- Tools typically use machine learning
- Comparison of actual output vs digital twin modelling
- Peer-to-peer comparison
- Ideally allows for prediction of faults



Forecasting

- Extensively presented before by Eli Shirazi
- Forecast serve various purpose and timescales
- They aid in economics of plant, e.g.:
  - possibilities for grid services,
  - day ahead markets
- But also serve technical purposes
  - Power plant control, grid compliance



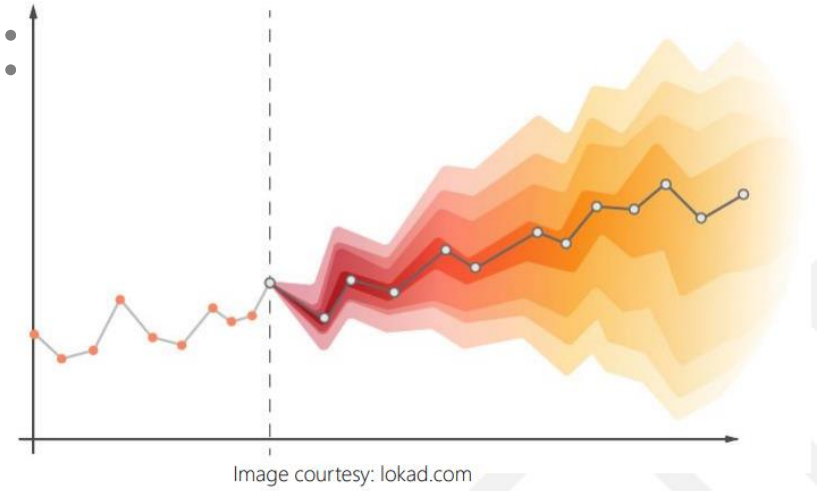
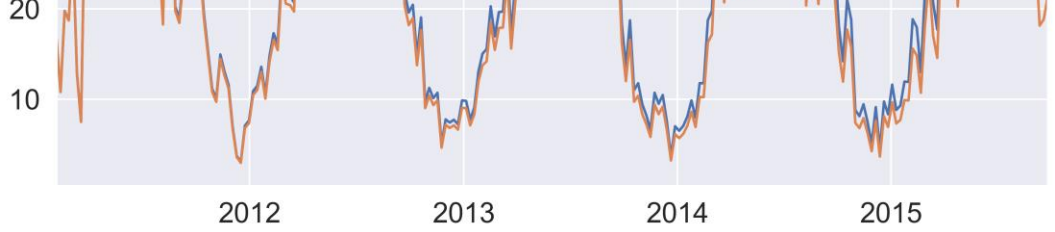


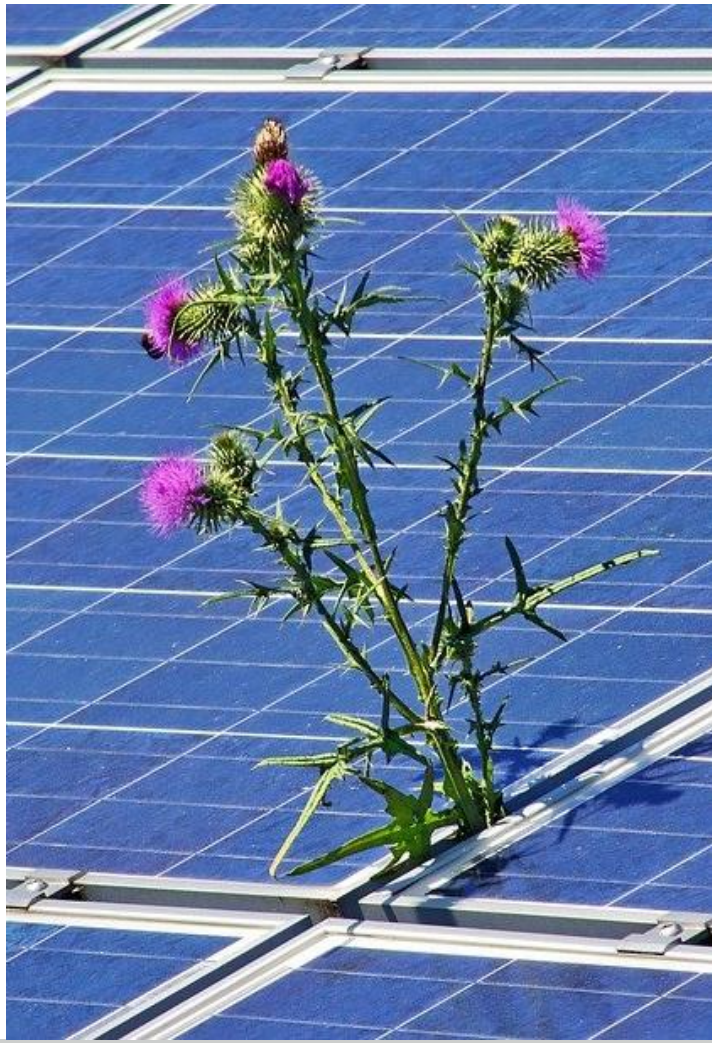
Image courtesy: lokad.com

Levering external data for quality checking

- By combining several data sources ground measurements can be validated
- Several companies offer such possibilities
- Can be used to assess plant performance and at the same time check sensor quality



Inspection + maintenance



Maintenance

- Preventive
- Predictive
- Corrective
- Extraordinary
- Vegetation control
- Soiling/cleaning

Inspection

- Inspection techniques
  - Thermography
  - EL
  - IV curve / electrical
  - Visual
- Aerial vs. ground based

Digitalization in Maintenance

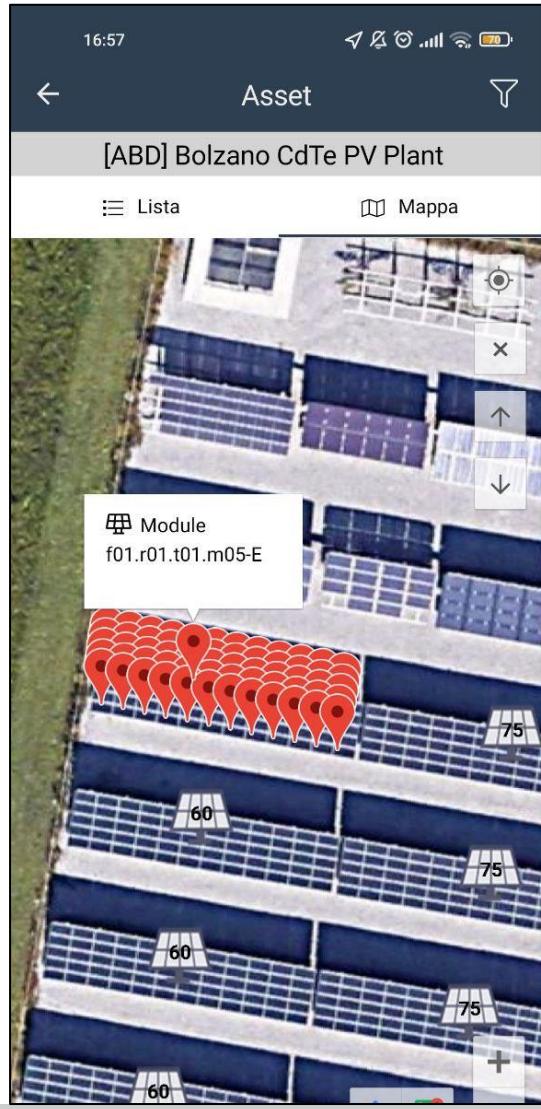
- First requirement is to move all maintenance logs to digital system
- Standardized!
- Collect all relevant information
- This allows valuable statistical insights in O&M activities, plant and component performance

Digitalization in Maintenance Workflows

- In project PV4.0 we aim to address this issue
- Too often maintenance logs are non-standardized or even paper based
- This does not allow any form of portfolio based statistical analyses
- Valuable insights are lost

Digitalization in Maintenance Workflows

- Applying a standardization of failures (risk matrix from SolarBankability)
- Developing app for technicians in the field
- Linked to asset management + digital twin
- Additionally, CPN method is implemented
  - Cost Priority Number
  - Evaluates economic impact of field failures
  - Allows for prioritization of tickets



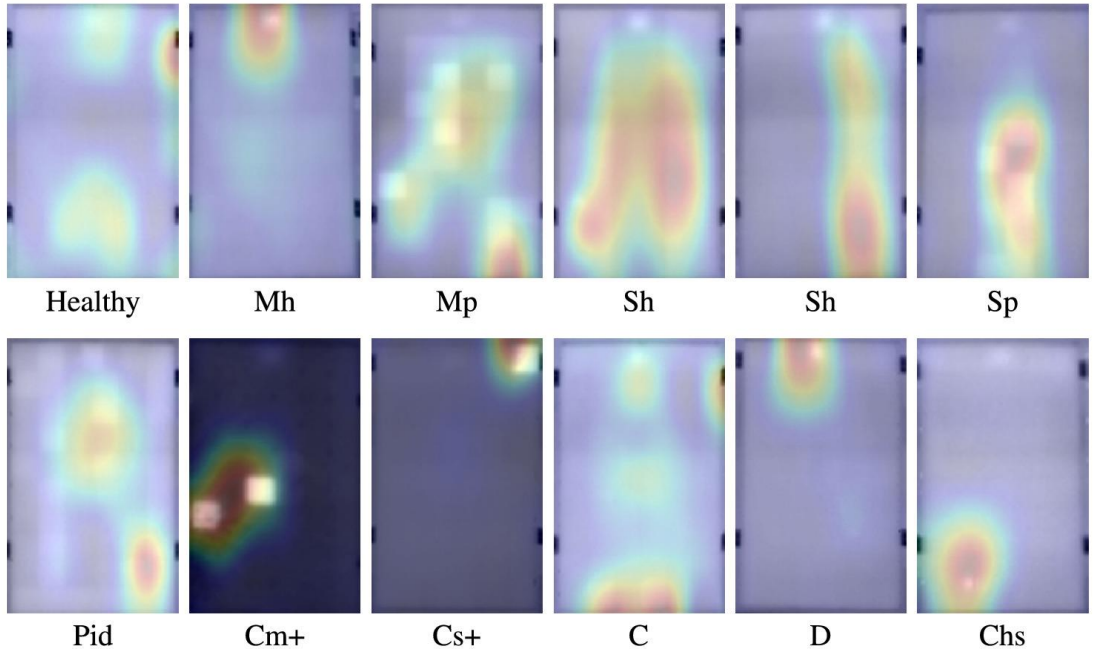
Inspection and digitalization

For inspection activities, digitalization can

- Improve existing, “old school” inspection
- Enable novel inspection techniques
- Potentially drastically improve efficiency and accuracy of inspection

Automatic detection of faults in inspection measurements

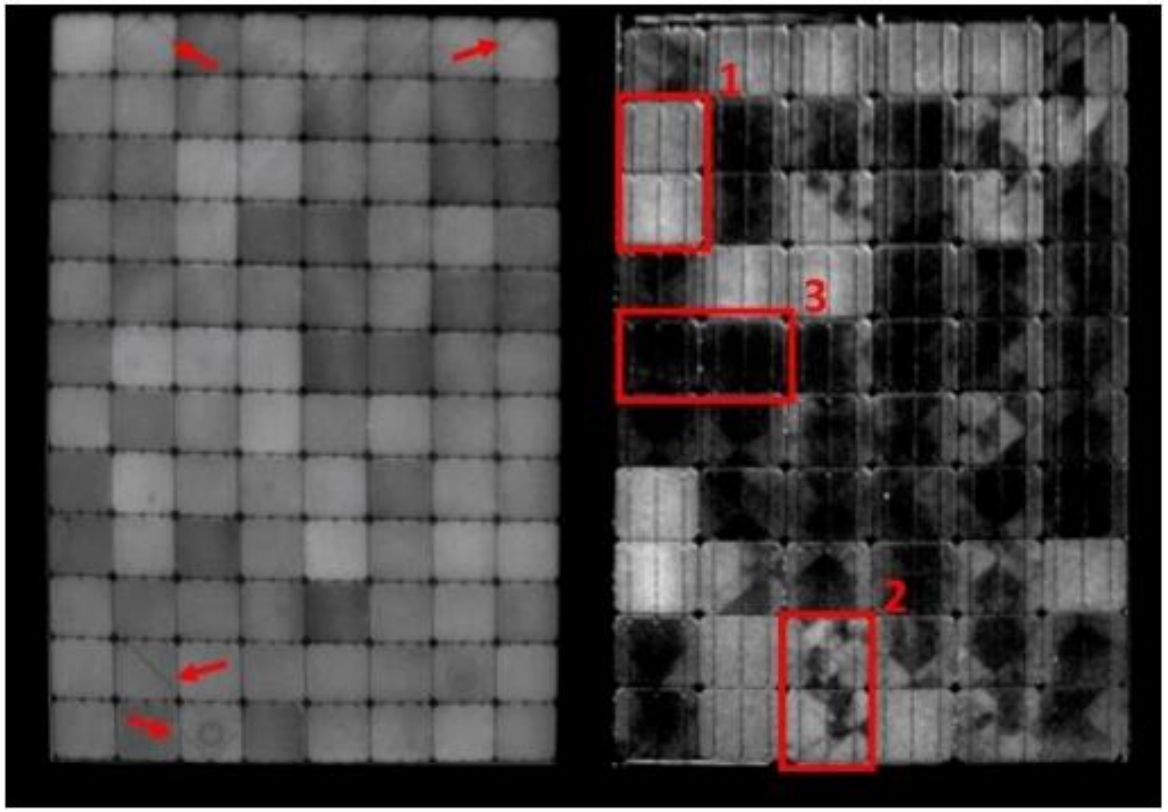
- Existing measurements can be automatically analyzed using machine learning
- To classify faults
- With proper interface of technicians to database
  - Training material is collected
  - Predictions improved



Bommes et al, 2021 https://doi.org/10.1002/pip.3448

Enabling new and more efficient inspection

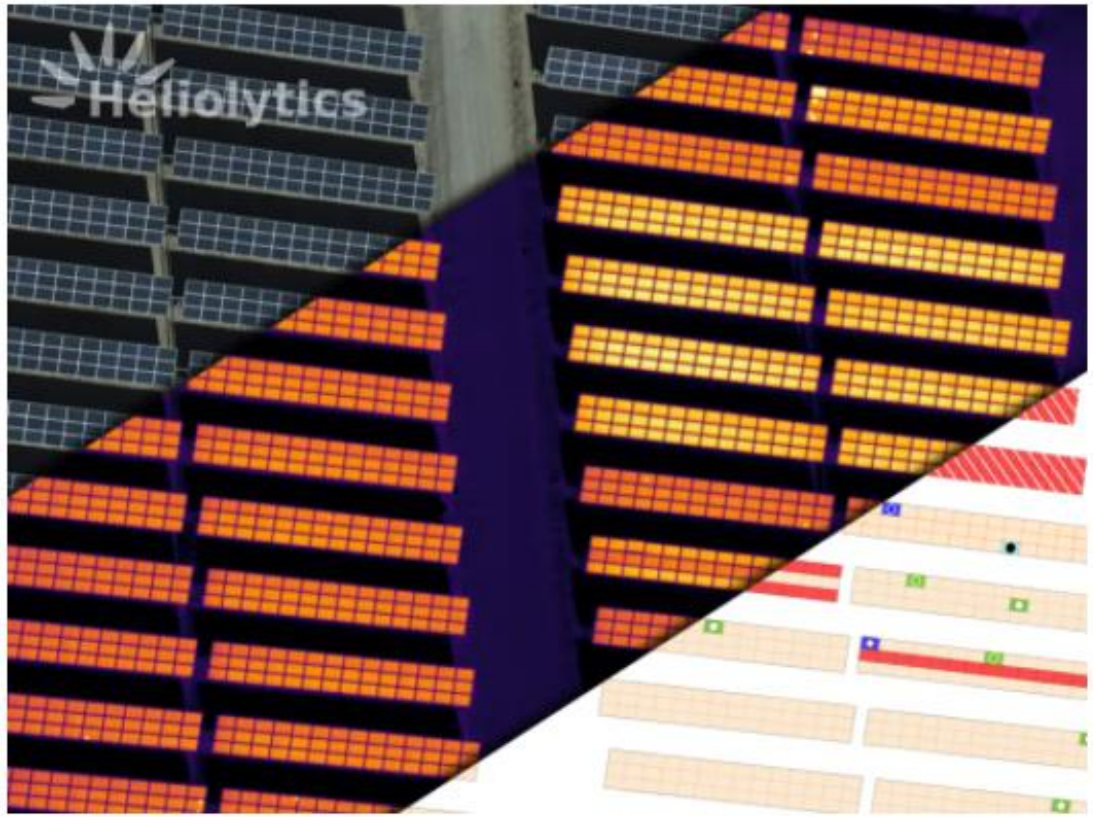
- By using smart digital approaches lab methods can come to the field
- daylight PL: allows for EL-like inspection during the day
- Allows for identification of power losses and root causes in PV modules



Koester et al, 2020
https://doi.org/10.4229/EUPVSEC20202020-4CO.4.2

Drone based inspections

- Several providers offer drone surveying
- Images are analyzed to
  - Detect PV modules in arrays
  - Geolocalize assets
  - Detect faults
  - Feed data into asset management / digital twins
  - Provide intervention suggestions



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Drone based inspections

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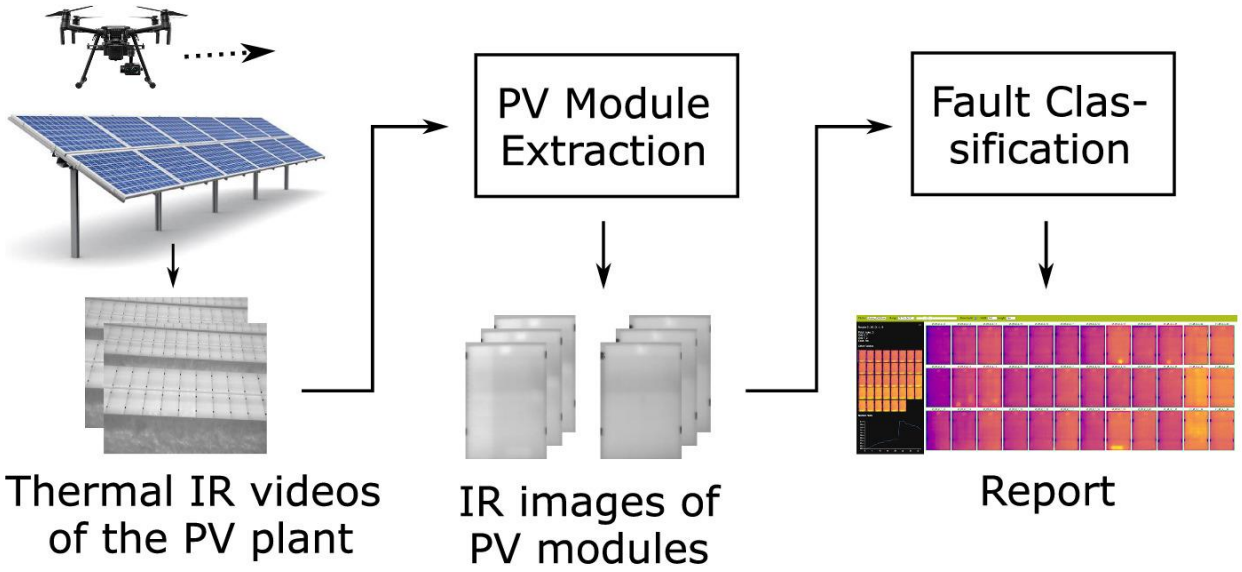

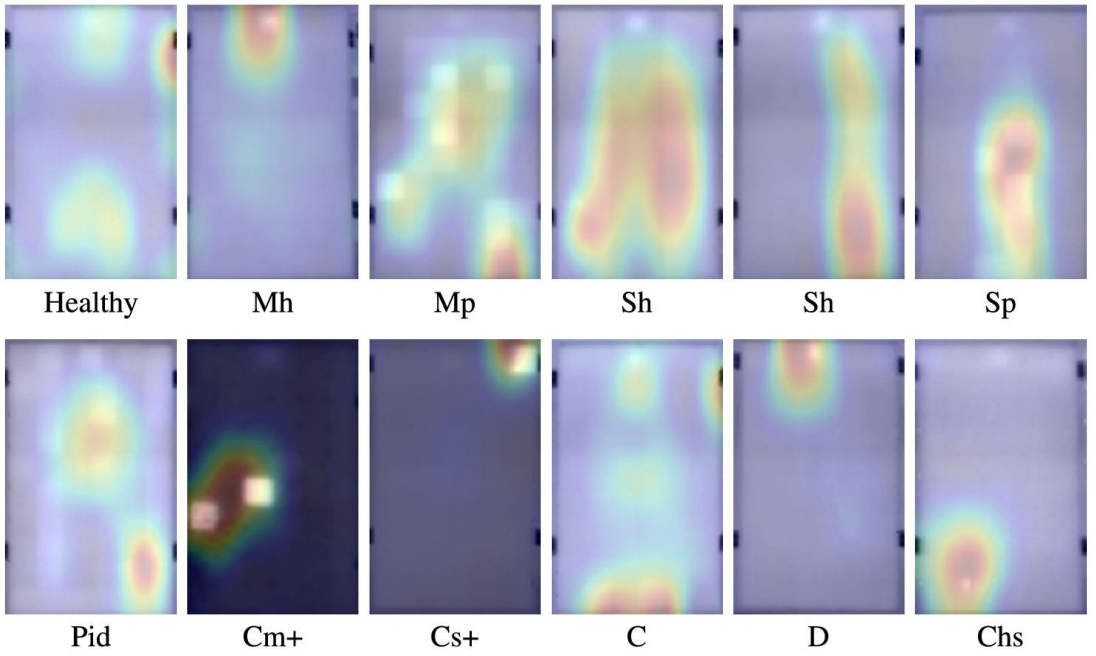

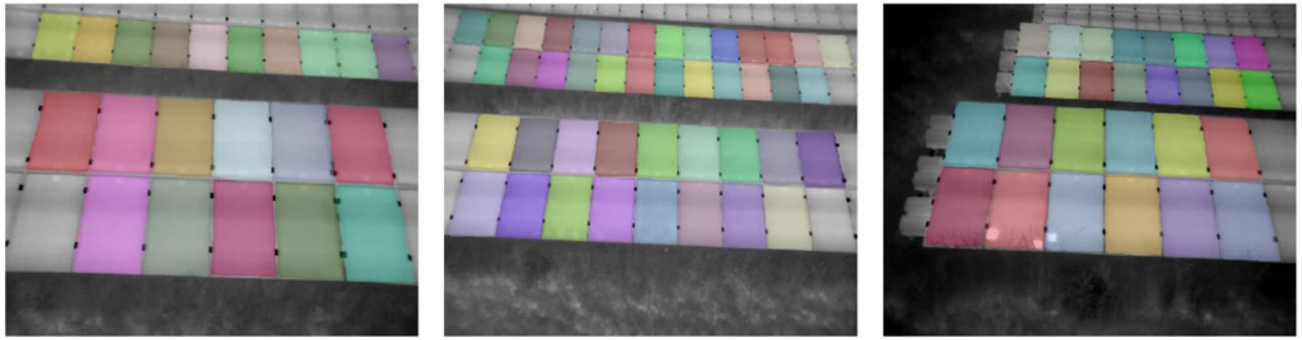

Drone based inspections

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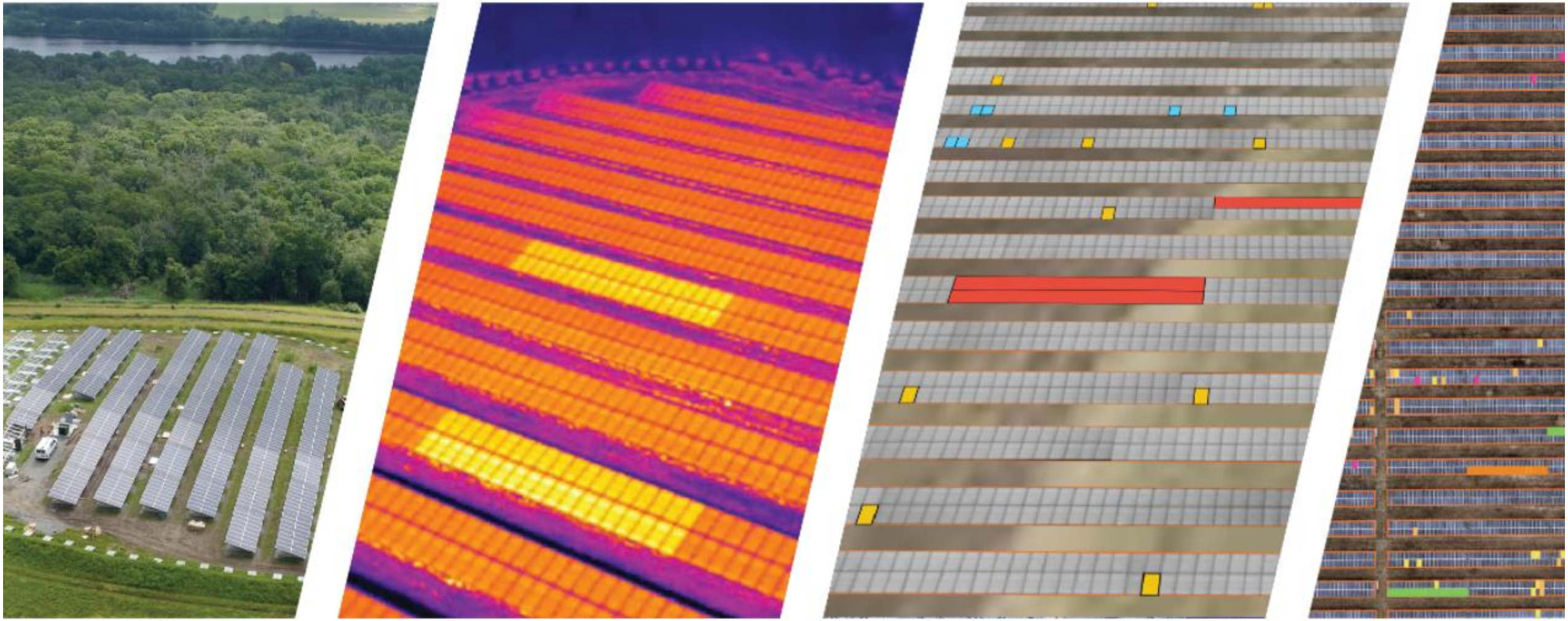
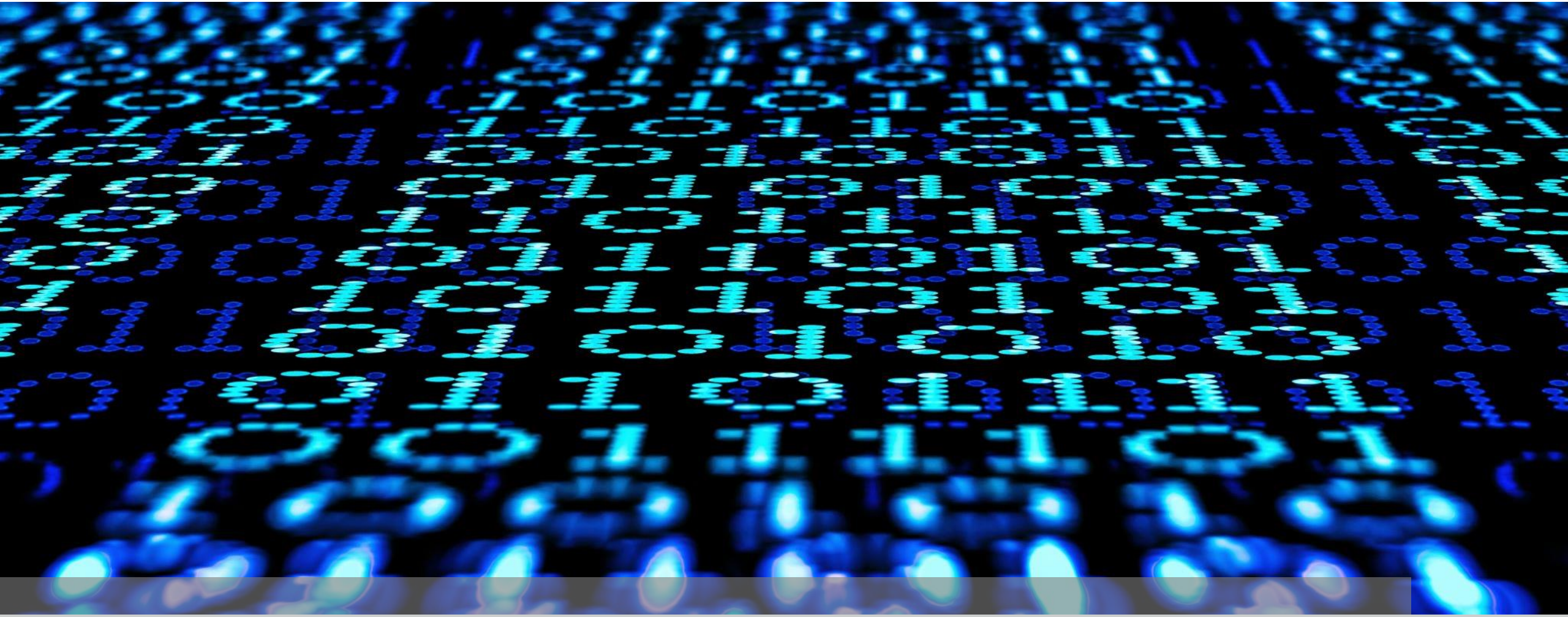


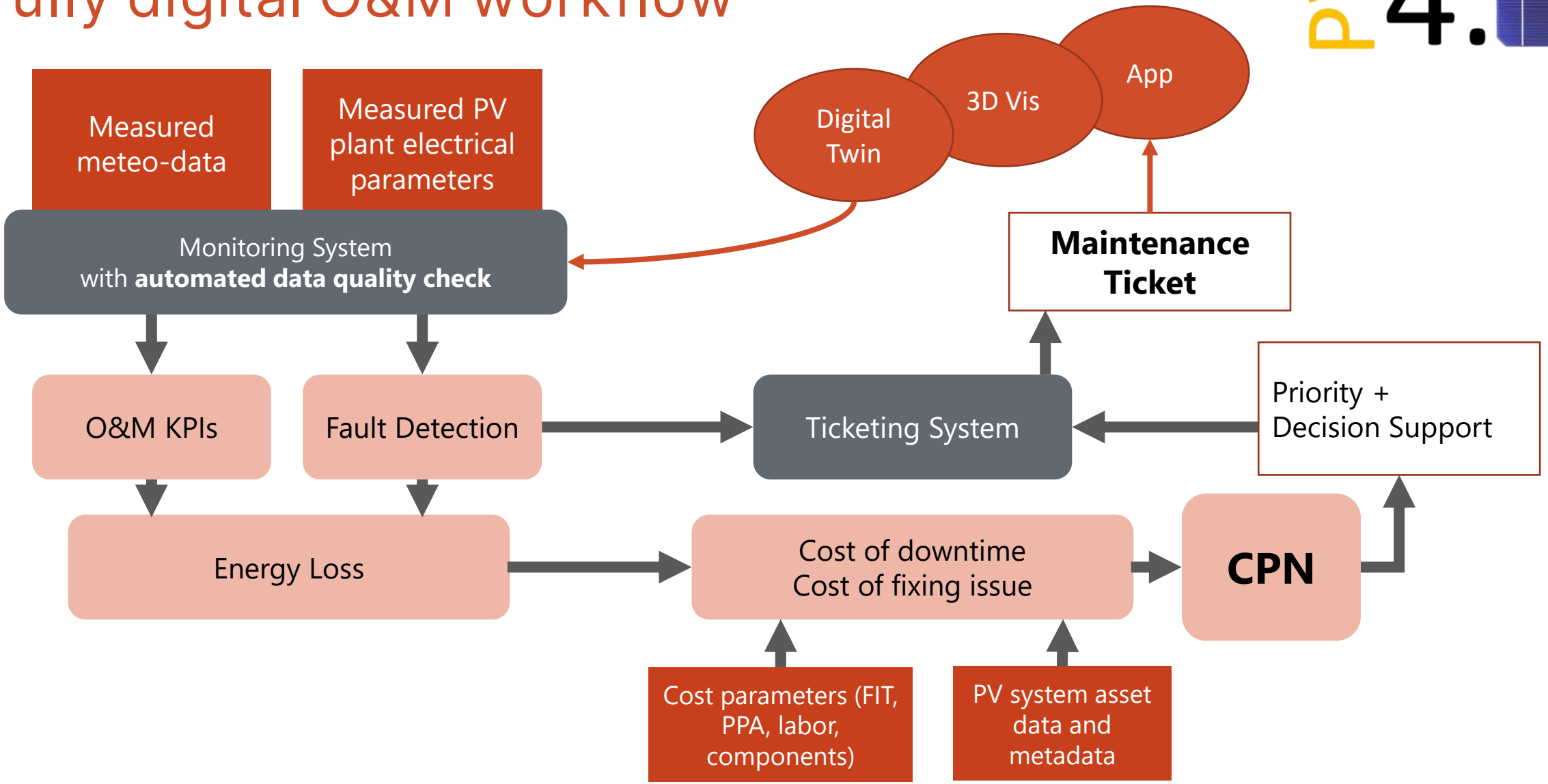
Combining Data Streams



Managing all data flows: PV plant asset management

- Considering a utility PV plant of several MW:
  - Roughly 3000 modules / MW
  - Area of ~10^5 m^2 / MW
  - thousands of meters of cables
  - Central or many distributed inverters
  - Potentially different module types
- Digital system essential to store and access data
- Serial numbers, spec sheets, spares, maintenance history, inspections, etc, etc
- Must be accessible for many different O&M people
- Feeds into and out of e.g. monitoring, maintenance/ticketing, inspection, digital twin, warranty and insurance claims

Fully digital O&M workflow



Decision Support Systems

- Most advanced application of digitalization
- DSS combines all “knowledge” and suggests interventions
  - For open maintenance issues
  - For preventive / predictive maintenance
  - Cleaning schedule, inverter checks, vegetation control, etc.
- DSS prevents overload of information, but distills it and prevents actionable information
- Quality metrics and large information database is necessary

Wrap-up

- In essentially all O&M related activities digitalization is ongoing and of great value
- With professionalization of the PV O&M sector, available tools are improving drastically
- Greatest benefits can be obtained by combining datastreams from different activities
- Many more improvements are needed and require PV researchers with digital skills

Thank you
for your attention!

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